THE HORIZONTALLY POLARIZED DIPOLE ANTENNA AS A SOLUTION TO THE PROBLEMS OF HIGH FREQUENCY SHORT RANGE COMMUNICATIONS

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THESIS

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by

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The Horizontally Polarized Dipole Antenna
As a Solution to the Problems of
High Frequency Short Range Communications

by

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TABLE OF ABBREVIATIONS

CVA	-	Attack Aircraft Carrier
db	-	Decibel
DD	-	Destroyer
FLTSATCOM	-	Fleet Satellite Communications System
HF	-	High Frequency
KW	-	Kilowatt
MHZ	-	Megahertz or one million cycles per second
NAVCOMMSTA	-	Naval Communications Station
NELC	-	Naval Electronics Laboratory Center

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I. INTRODUCTION

Currently, communications between shore stations and U. S. Naval vessels is conducted using high frequency radio circuits. Present planning indicates a gradual conversion to satellite communications, with the U. S. Navy using its own Fleet Satellite Communications System (FLTSATCOM) by 1980 [2]. It must be realized, however, that HF radio is still the primary means of ship/shore communications within the Navy and will be so until 1980, assuming there are no delays beyond the many that have already been experienced in the FLTSATCOM program. Furthermore, beyond 1980, it is envisioned that HF radio will continue to play a major role in intra task force communications. A final area that must be considered when discussing the future of HF communications, is that of Naval Inshore Warfare, specifically communications between the forward operating base and the personnel involved in a particular task.

In 1969, initial decisions were made to replace HF radio gradually as the primary means of ship/shore communications. The U. S. Navy's first communications satellite was launched shortly thereafter, and used successfully until December 1972, with certain major combattant ships using it on an interim, trial basis for ship/ship, ship/shore and ship/air communications. Since the first successful use of this satellite

(TACSAT I), very limited funding has been available for the upgrading of HF systems, as the majority of all communications funding has been directed toward satellites.

II. THE PROBLEM

A. DEFINITION

The primary method of HF communications within the U. S. Navy is with vertically polarized antennas. These antennas permit communications over short ranges via ground wave propagation and for ranges over three hundred miles via sky wave propagation. The difficulty arises in attempting to communicate within the skip zone. That is, the area from the limit of the useful ground wave to the distance where the ionospheric sky wave can be received. Figure 1 illustrates the expected ship-to-ship ground wave communications range, using a one kilowatt power output transmitter with an 85% reliability requirement, in the summer months, during the hours of midnight to 0400. The chart represents various noise areas of the world [11]. Several conclusions can be drawn from this chart. The obvious conclusion is that ranges out to 300 miles (the range considered as the beginning of satisfactory sky wave propagation) can only be reached in low noise areas. Were the U. S. Navy to operate primarily in low noise areas, the problem would be greatly reduced. However, this is not the case. Areas of high noise that will result in severe range reduction are typically within 1000 miles of land masses between 20 degree North and 20 degrees South. The areas within 1000 miles of the East

coast of the United States and the South China coast are high noise areas in the summertime. The Mediterranean Sea and the Indian Ocean are considered moderate noise areas.

B. SHIP/SHORE DIFFICULTIES

Using a typical 8db shipboard antenna (8db nulls less than 10% of the time), with transmitter power output of one KW, in high noise areas performance will be considerably below the 300 mile range between the hours of 1600 to 2400 and 2400 to 0400. The use of better antennas (those capable of 4db nulls less than 10% of the time), coupled with raising transmitter power to five KW still falls short of the 300 mile mark by 100 miles. In moderate noise areas of the world, the ships with the superior 4db antennas, using five KW transmitter power can marginally be expected to reach a 300 mile range when transmitting on a frequency of two MHZ. Even in low noise areas of the world, using a typical 8db shipboard antenna, the 300 mile groundwave requirement will not be met between the hours of 2000 to 2400 [12]. An additional factor to take into consideration is that numerous smaller ships such as patrol craft and patrol gunboats are equipped with transmitters with output power of only 100 watts. Figure 2 depicts the expected average decrease in the ground wave communications range using a 100 watt rather than a one KW transmitter [12].

In summarizing the problem as analyzed, those ships with transmitters capable of one KW output can expect to communicate

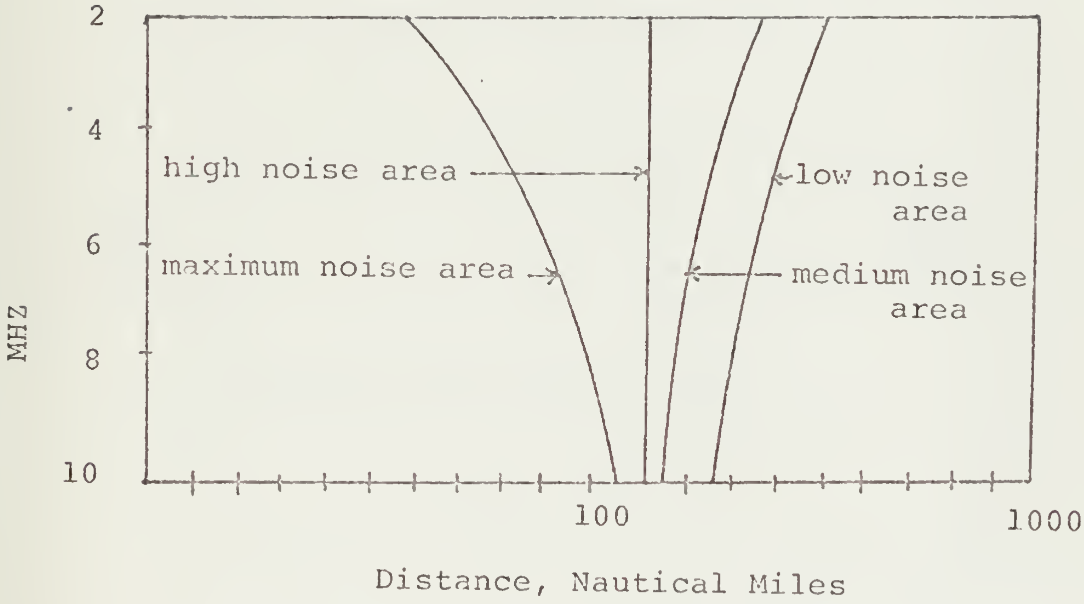


Figure 1

Expected Ship to Ship Groundwave Communications Range.

Lines represent various noise areas of the world.

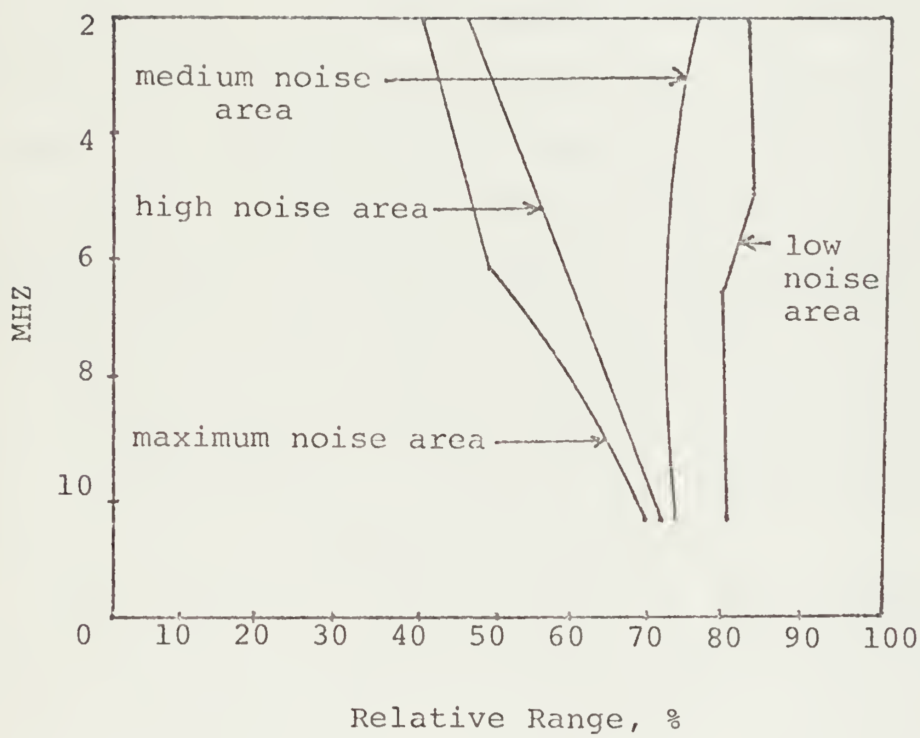


Figure 2

Expected Average Decrease in the Groundwave Communications Range Using a Small Ship, 100 Watt Transmitter

via groundwave propagation beyond the 200 mile range only when operating in low or moderate noise areas of the world. Ships equipped with transmitters capable of only 100 watt output cannot expect to transmit further than 100 miles using groundwave propagation in high noise areas.

C. SHORE STATION DIFFICULTIES

In discussing the problem of transmitting from the shore station to the ship, it must be remembered that transmitter power of much greater magnitude is available. For this reason, most shore stations have a preponderance of vertically polarized antennas. In reality, the high frequency ground wave transmitted from the shore station is not much more effective than that of the ships. In cases where the transmitting antennas are not located directly on the coast line, but rather are some distance inland, the groundwave becomes almost useless as it is absorbed by the earth.

The primary operating areas of the U. S. Naval vessels are generally within the 100 to 300 mile range of the local Naval Communications Station. (Virginia Capes operating area and NAVCOMMSTA Norfolk, Northern California operating area and NAVCOMMSTA San Francisco, Southern California operating area and NAVCOMMSTA San Diego). In a study conducted by the Naval Electronics Laboratory Center in 1971, [13], the need for the high angle HF antennas to cover short range was recognized. However, those commercially available high angle antennas capable of receiving and transmitting at two MHZ were very large, expensive structures which would

cause interaction and distortion of other antennas in a field the size of a normal Naval Communications Station.

III. ANTENNA TESTING

A. COMPARISONS

NELC submitted a report on the results of an HF high angle short range antenna test conducted in 1970 [9]. It was the conclusion of this report that horizontally polarized antennas of circular or linear polarization were about equally effective in providing the required upward directed power gain for short distance communications. Vertically polarized antennas were increasingly ineffective as distances were decreased toward zero. The antenna comparison criterion was based on signal to noise ratio in that experiment and was most critical in the first 150 miles of ground distance. Combinations of antennas were used to determine combinations of receiving and transmitting polarizations and antenna design patterns that would be most effective for high angle, short range, HF communications. The transmitter site and each of three receiver sites used six different antenna types: (1) Normal dipole (horizontal), (2) In-line dipole (horizontal), (3) crossed dipoles (horizontal), (4) Left-hand circular polarized dipole (horizontal), (5) Right-hand circular polarized dipole (horizontal), (6) Whip (vertical). Measurements were done simultaneously for all receiving antennas. The transmitting site was located at Curtis Bay, MD. The receiving sites were located at distances of 54

miles south, 150 miles northeast, and 310 miles northeast. Both day and night transmissions were used, at frequencies from three MHZ to 6.835 MHZ. Results of the test are summarized as follows:

(1) Normal dipole transmitting.

a. The horizontal receiving antennas have equal performance.

b. The receiving whip has a poorer signal to noise ratio by 11db.

(2) In-line dipole transmitting.

a. The horizontal receiving antennas have about equal performance.

b. The receiving whip has a poorer ratio by 7db.

(3) Crossed dipoles transmitting.

a. The horizontal receiving antennas have equal performance.

b. The receiving whip has a poorer ratio by 6db.

(4) Right circular polarized transmitting.

a. Receiving on left circular polarized has a 5db advantage over the other horizontally polarized antennas.

b. The receiving whip has a poorer ratio than the left circular polarized by 17db and is poorer than the other horizontal antennas by 12db.

(5) Left circular polarization transmitting.

a. Equal performance by horizontal antennas except for the circular polarized which was down by 11db.

b. The receiving whip is down by 17db.

(6) Vertical whip transmitting.

a. All horizontal receiving antennas about equal.

b. Vertical receiving whip is down by 9db.

All of the above results can be interpreted by reversing the transmitting and receiving situation (i.e., all horizontal transmitting antennas give 8 to 9db better performance than the transmitting vertical whip, when receiving on a vertical whip.

B. INTERPRETATION OF RESULTS

The results of this experiment bear out the difficulties that shipboard communicators have faced for years, and continue to face. The need for a horizontally polarized shipboard antenna is glaring. Shipboard communicators would be well advised to improvise, if horizontal dipole antennas are not to be designed for their needs. A horizontal wire receiving antenna could be readily installed (many ships do have horizontal wire antennas used for various purposes) and used for distances within the skip zone. Some of the general purpose shipboard receiving antennas capable of operating throughout the lower end of the HF band should be redesigned to enhance high angle radiation if they are to be used for short range communications. The antenna configuration of an aircraft carrier should be reviewed. The majority of the receive antennas aboard a CVA are located on the edge of the flight deck, forward of the superstructure. To enable flight operations, the antennas can be readily

lowered to the horizontal position, thus removing them as an obstacle to aircraft being catapulted from the deck. To preclude continuously raising and lowering the antennas, most aircraft carrier leave them lowered in the horizontal position during operational periods. Although not designed as a horizontally polarized antenna, this placing of the whips in the horizontal position has the effect of polarizing the antennas in the horizontal plane. The effect, although not documented, has been verified by the authors experience while communications officer aboard a CVA in the Western Pacific. While operating within the skip zone, receive signals were noticeably improved with the antennas in the horizontal position. Reception generally paralleled that expected by the DD's in company when the antennas were vertical, with the CVA being of minimal assistance in relaying missed messages to the DD's during this time. However, with the antennas horizontally polarized, HF reception aboard the CVA was considerably superior to that aboard the DD's with the CVA's task of relaying missed messages increased as a result. The possibility of providing other ship types with whip antennas capable of being lowered to the horizontal plane should be investigated.

IV. MODEL TESTING

In December of 1975, in conjunction with this thesis, a series of three horizontally polarized antennas were tested at the model range of the Naval Electronics Laboratory Center, San Diego. The model used was that of the USS Belknap. Antennas used were the two to six MHZ fan antenna, the stern twin whip in the horizontal position, and a resonant length horizontal dipole strung between the after mast and the fantail. Figures 70 and 71 of Appendix A show the models and antennas actually used in this test. Figure 70 shows the ship looking from the stern, with a view of the twin whip in the horizontal position. The wire dipole and the fan antenna can be seen clearly in figure 71. Two frequencies were measured, corresponding to 3.42 MHZ and 10 MHZ. At each frequency, and for each antenna, elevation measurements were taken at 000 degrees, 045 degrees, and 090 degrees relative bearing, and azimuth patterns at 5, 10, 20, 30, 40, 50 and 60 degrees elevation, for a total of ten patterns for each antenna at each frequency. Both vertical and horizontal polarizations were taken. These antenna radiation patterns are included as figures 10 through 69 of Appendix A.

A series of tables has been constructed to show gain as a function of elevation angle. These tables are displayed

as figures 3 through 8. Column one of each table represents the elevation angle. Column two shows the ideal great circle distance in kilometers, assuming an ionospheric layer height of 300 Km [3]. Column three is the approximated average of the horizontal component in decibels below the zero db ring on the chart. Column four is the calculated gain relative to a quarter wave monopole antenna under the same parameters.

An examination of the patterns produced by the horizontal wire dipole, figures 10 through 29, shows that the horizontal component has two nulls, one almost directly forward, and one almost directly aft of the ship's heading. As the antenna is oriented nearly in line with the ship's heading, and as the nulls are relatively consistent at both frequencies and at all of the higher angles, this indicates that an additional antenna would be required, in conjunction with the dipole, to provide 360 degree coverage. As the distances of intended transmission are relatively short for the purpose of these antennas (zero to 300 miles), and since the nulls are predictable and within a narrow range (30 degrees directly ahead and astern), a dipole antenna of less than a quarter wave, mounted athwartships, should suffice. Additionally, figures 50 through 69 indicate that the twin whip experiences nulls in line with its orientation. If a similar whip was mounted on either side of the ship's stern, facing onboard and perpendicular to the ship's centerline, and used in conjunction with either the stern whip or the dipole, the nulls should be eliminated. The

fan antenna displays a less predictable pattern than either the dipole or the whip. This is most likely attributable to its location amidships between the ship's stack and superstructure. An examination of figures 38 and 39 reveals a relatively stable pattern at 50 and 60 degrees elevation on 3.42 MHZ, while figures 48 and 49 display additional nulls in the pattern of the fan at 10 MHZ.

A few general observations are made at this point, concerning the gain of the three antennas as calculated relative to that of a quarter wave monopole. Referring to figures 3 and 4, it can be observed that the gain of the horizontal dipole, at both frequencies, measured at 50 and 60 degrees elevation, is superior to that of a monopole. The fact that a full resonant dipole was used for this test, as opposed to a quarter wave or smaller, must be considered. However, as previously stated, the transmission distances in question are low enough to relegate gain to a minor role. Examining figures 3 through 8, it can be determined that at the 60 degree elevation point, the worst case is that of the fan antenna transmitting at 3.42 MHZ and experiencing a loss of 3.88db below that of the monopole. Even in this case, discounting the nulls, the signal loss should not present a problem.

Degrees Elevation	Ideal Distance (Km)	Average Gain of Horizontal Comp.	Gain Relative to a ¼ Wave Monopole
5	2900	-35db	-14.88db
10	2300	-30db	- 9.88db
20	1500	-25db	- 4.88db
30	900	-22db	- 1.88db
40	650	-21db	- .88db
50	450	-20db	.22db
60	300	-19db	1.22db

Figure 3

Gain calculations for the horizontal component of the Resonant Horizontal Dipole at 3.42 MHZ

Degrees Elevation	Ideal Distance (Km)	Average Gain of Horizontal Comp.	Gain Relative to a ¼ Wave Monopole
5	2900	-25db	-7.88db
10	2300	-14db	3.12db
20	1500	-13db	4.12db
30	900	-13db	4.12db
40	650	-14db	3.12db
50	450	-16db	1.12db
60	300	-16db	1.12db

Figure 4

Gain calculations for the horizontal component of the Resonant Horizontal Dipole at 10 MHZ

Degrees Elevation	Ideal Distance (Km)	Average Gain of Horizontal Comp.	Gain Relative to a ¼ Wave Monopole
5	2900	-25db	-7.88db
10	2300	-17db	.12db
20	1500	-16db	1.12db
30	900	-16db	1.12db
40	650	-17db	.12db
50	450	-18db	- .88db
60	300	-19db	-1.88db

Figure 5

Gain calculations for the Fan Antenna

(horizontal component) at 10 MHZ

Degrees Elevation	Ideal Distance (Km)	Average Gain of Horizontal Comp.	Gain Relative to a ¼ Wave Monopole
5	2900	-30db	-16.88db
10	2300	-28db	-14.88db
20	1500	-23db	- 9.88db
30	900	-21db	- 7.88db
40	650	-19db	- 5.88db
50	450	-18db	- 4.88db
60	300	-17db	- 3.88db

Figure 6

Gain calculations for the horizontal component of the Fan Antenna at 3.42 MHZ

Degrees Elevation	Ideal Distance (Km)	Average Gain of Horizontal Comp.	Gain Relative to a ¼ Wave Monopole
5	2900	-31db	-15.88db
10	2300	-25db	- 9.88db
20	1500	-20db	- 4.88db
30	900	-17db	- 1.88db
40	650	-15db	.22db
50	450	-14db	1.22db
60	300	-12db	3.22db

Figure 7

Gain calculations for the horizontal component of the stern Twin Whip in the horizontal position at 10 MHZ

Degrees Elevation	Ideal Distance (Km)	Average Gain of Horizontal Comp.	Gain Relative to a ¼ Wave Monopole
5	2900	-37db	-17.88db
10	2300	-35db	-15.88db
20	1500	-27db	- 8.88db
30	900	-25db	- 6.88db
40	650	-22db	- 4.88db
50	450	-21db	- 3.88db
60	300	-20db	- 2.88db

Figure 8

Gain calculations for the horizontal component of the stern Twin Whip in the horizontal position at 3.42 MHZ

V. THE SHORE STATION

A. PRACTICAL SHORE STATION TRANSMITTING ANTENNAS

1. Criterion

The criteria for selecting a suitable antenna for HF transmission in the horizontal plane are size, bandwidth, efficiency, power handling capability, and cost. Following is a brief summary of some of the commercially available high angle antennas, including advantages and disadvantages. Information on the antennas was provided by Mr. J. L. Heritage of the Naval Electronics Laboratory Center, in discussions and notes provided by him.

2. Down Directed Log Periodic Antenna

The vertically oriented, down firing, log periodic antenna is one of the best antennas, technically, for short range transmitting. It has wide bandwidth and high gain when erected over good earth or a metallic ground screen. Since its main energy is upward directed by reflection from the ground, erection over poor ground reduces its power gain. The major problem comes with interaction with other antennas. It is a very large antenna, both in height and area occupied. The TCI model 530 uses a 133 foot tower and measures 450 feet between guy anchors. It maintains uniform azimuth coverage and circular polarization by using essentially two planar arrays combined at right angles.

3. Horizontal Log Periodic Antenna

When shore to ship short range coverage is confined to 180 degrees, such as on the coast line, the horizontal log periodic antenna can provide a few db greater gain down to lower elevation angles while retaining good gain directly overhead. The TCI 501 is an example of this type of antenna. Once again the problem of size is involved, as well as that of cost. The TCI 501 requires a 140 foot tower and 3.7 acres of space.

4. Log Spiral Antennas

Log spiral antennas have good bandwidth and directivity patterns for short range HF transmission, but the two commercially available models, Granger 789 and Collins 637 require terminating resistors at frequencies down to two MHZ, thus reducing power output by as much as one-half at the lower HF frequencies, the range where it is needed the most.

5. Horizontal Dipole

A horizontal dipole meets nearly all requirements of a shore station transmitting antenna, except it is limited in bandwidth. The Granger model 1765, designed for use between two and eight MHZ is an example. The height and length dimensions chosen by Granger in this antenna probably reflect an attempt to get maximum overhead gain and a good impedence match at two MHZ.

A similar dipole was tested by NELC [9] with the antenna length reduced to 166.5 feet. Good power gain was

achieved. A broadband dipole of these dimensions could easily be erected on standard telephone poles at low cost. Two such dipoles would be required, one to cover the two to six MHZ range and one for the six to eighteen MHZ range. This system would require the availability of narrow-band tuned multicouplers. If these are not readily available, it may still be cost effective to consider a group of low cost dipoles, each in a narrower frequency band. Low sited horizontal dipole antennas have an advantage over large broadband antennas in lower interaction with neighboring vertical antennas, causing minimal radiation pattern distortion to both antennas. Less land space would be required for two dipoles than for any of the broadband antennas. Two dipoles in line can share a common pole and less guying is required. This type of antenna arrangement was successfully tried by NAVCOMMSTA San Diego on a self-help basis. Many other communications stations still operate without the use of a horizontally polarized antenna system.

B. SHORE STATION RECEIVING ANTENNAS

The log periodic and log spiral antennas mentioned in the transmitting antenna section will make adequate receiving antennas. Efficiency is not as important in receiving antennas and one antenna can be easily multicoupled to several receivers. To provide antenna diversity, at least two receive antennas should be installed at each shore station receiver site. Placed at right angles to each

other, they would provide the directional capability required. Again, the simple dipole antenna, sited low, should be the most effective receiving antenna for this purpose [9]. It should be possible to operate successfully over the range from two to ten MHZ in a single antenna.

VI. CONCLUSIONS

A. THE SIMPLE DIPOLE

In the 1971 NELC study [13], it was pointed out that a simple, crossed dipole receiving antenna would be effective for receiving on high angle, ionospherically propagated, ship/shore circuits. Low antenna heights, using telephone poles would yield satisfactory directional patterns at high angles over a frequency range of two to ten MHZ. Some mismatch could be tolerated at the lower frequency, enabling the dipoles to be kept short. The recommendation was made that development be undertaken to produce a small, inexpensive, horizontally polarized dipole antenna that would operate satisfactorily over the entire HF band.

Recently, design and testing of such an antenna was conducted by Collins Radio Corporation to solve the problems of short range communications for tactical military ground forces [1]. A simple dipole and coupler was designed, with tuning components consisting of a series compacitor, a shunt capacitor, and a shunt inductor. The antenna operates best at a height of approximately 20 feet above ground, providing high angle radiation up to 15 MHZ and tuneable up to 30 MHZ. A sketch of the Collins design is provided in figure 9.

A problem that must be considered when discussing the possible use of such an antenna aboard ships is the fact that

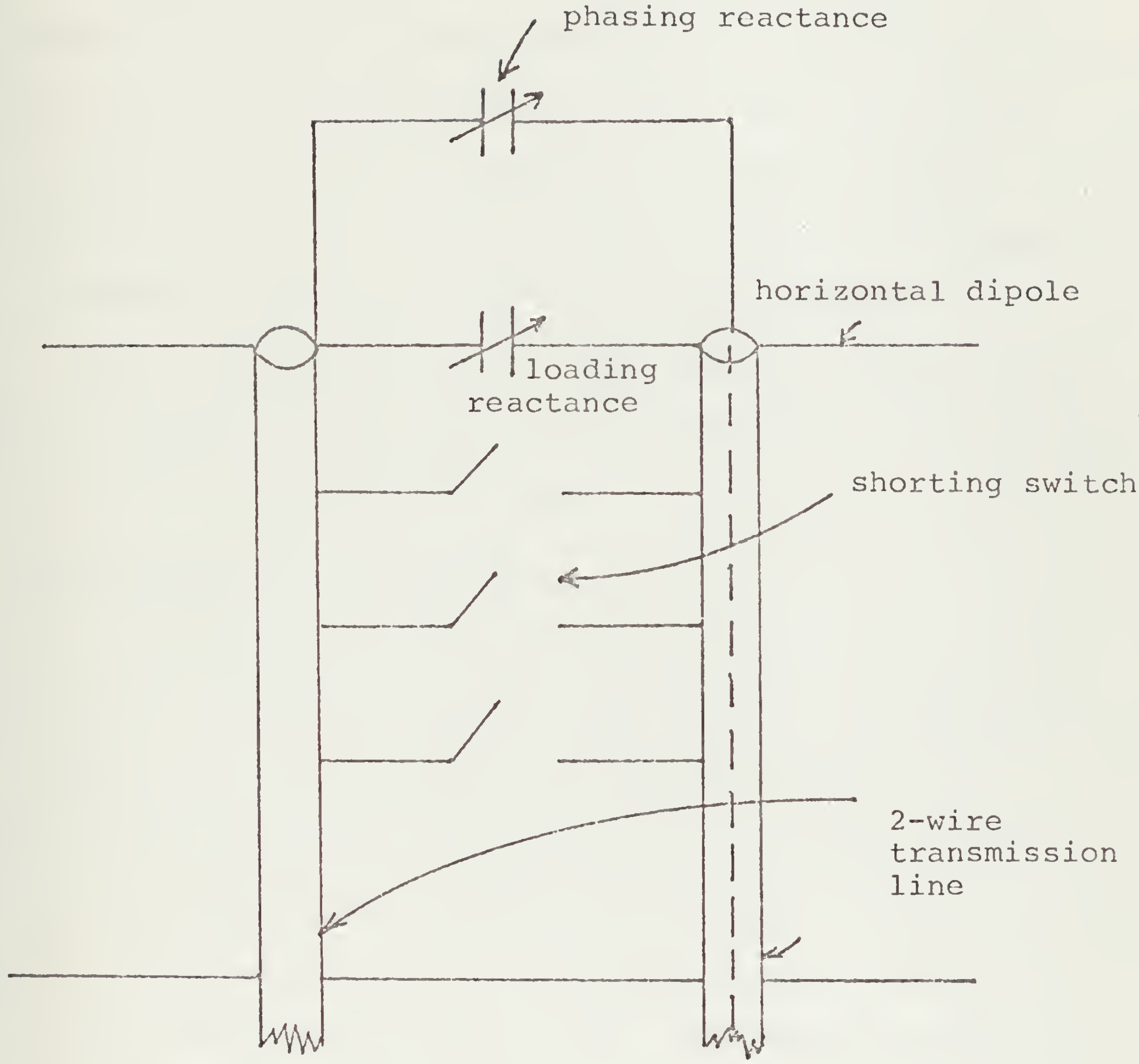


Figure 9

Collins horizontal quarter-wave dipole antenna design [9]

horizontal dipoles are directional. The problem is not insurmountable, however, and could be readily solved by installing two quarter wave dipole antennas mounted perpendicular to each other in the horizontal plane. By designing the antenna system for one-quarter wavelength at 10 MHZ, the length of the the antennas could be kept under twenty-five feet, enabling it to fit on virtually all Naval vessels. Installation of such an antenna at the shore stations could be accomplished with little difficulty and minimum cost. Due to the relative simplicity of the antenna, a satisfactory horizontal dipole of the type discussed could be easily built and installed by station personnel.

B. THE HORIZONTAL CONE ANTENNA

As an interesting additional observation, a study of the mast structures of Soviet Naval ships reveals the presence of a cylindrical pair of horizontal antennas mounted at approximately a 90-degree angle to each other, high on the mast of many of the larger vessels [7]. These antennas are obviously designed for the high frequency range, and are most likely used for high angle, short range communications. Although it is beyond the scope of this paper, a model design and test of such an antenna for short range communications would appear to be a valuable undertaking.

C. COST ANALYSIS

A very brief cost analysis is presented to provide some idea of costs involved. In the case of many of the shore

stations, installation of dipoles could be carried out by station personnel, using available equipment. Shipboard installations would require shipyard assistance. This could be carried out during routine shipyard availability periods.

Estimated installation costs of a dipole antenna aboard a Naval vessel, based on information provided by the electronics installation estimators at Mare Island Naval Shipyeard, include fifteen man days at the current price of $19.00 per hour for an eight-hour day, with total installation cost estimated at $2280. If available cable runs could be used, such as could be done if installed whip antennas were converted to horizontal dipoles, the price of installation would be reduced considerably. Equipment costs would also be greatly reduced if the cable runs were available.

Commercially available horizontally polarized dipole transmitting antennas for shore station use are currently priced at $13,900. Commercial installation cost in the U. S. is $20,000 while on Guam it would be $40,000.

D. ALTERNATIVES

In conclusion, a final look at the alternatives should be made. Present planning appears to call for continued all-out effort to complete the Navy satellite communications system, with all available funding being channelled in this direction. This relegates ship/shore communications, and especially short range communications to remain in their present unsatisfactory condition until at least 1980.

Another alternative under discussion consists of closing down HF entirely as a means of ship/shore communications after the satellite system is operational. In response to this alternative, a hard look at the experience of the CVA's in the Western Pacific in 1971 and 1972 in using TACSAT should be taken. Based on the writer's experience during this period, the success of satellite communications remains unproven.

The final alternative is, of course, the one recommended throughout this paper. That is, to provide a minimum of funding for the development of a shipboard horizontally polarized HF dipole antenna, and to install commercially available dipoles at Naval Communications Stations around the world. As an interim measure, these antennas should be installed by any available means, using designs tested and proven satisfactory by NELC. Failure to do so is to continue to ignore a major problem in Naval communications, hoping that by some change it will go away.

APPENDIX A:

ANTENNA RADIATION PATTERNS AND ANTENNA PHOTOS

The appendix consists of sixty antenna radiation patterns, taken in December 1975 in conjunction with this thesis, as well as photographs of the ship model and antennas used for the test. The individual patterns are numbered as figures 10 through 69 and the photographs are numbers as figures 70 and 71.

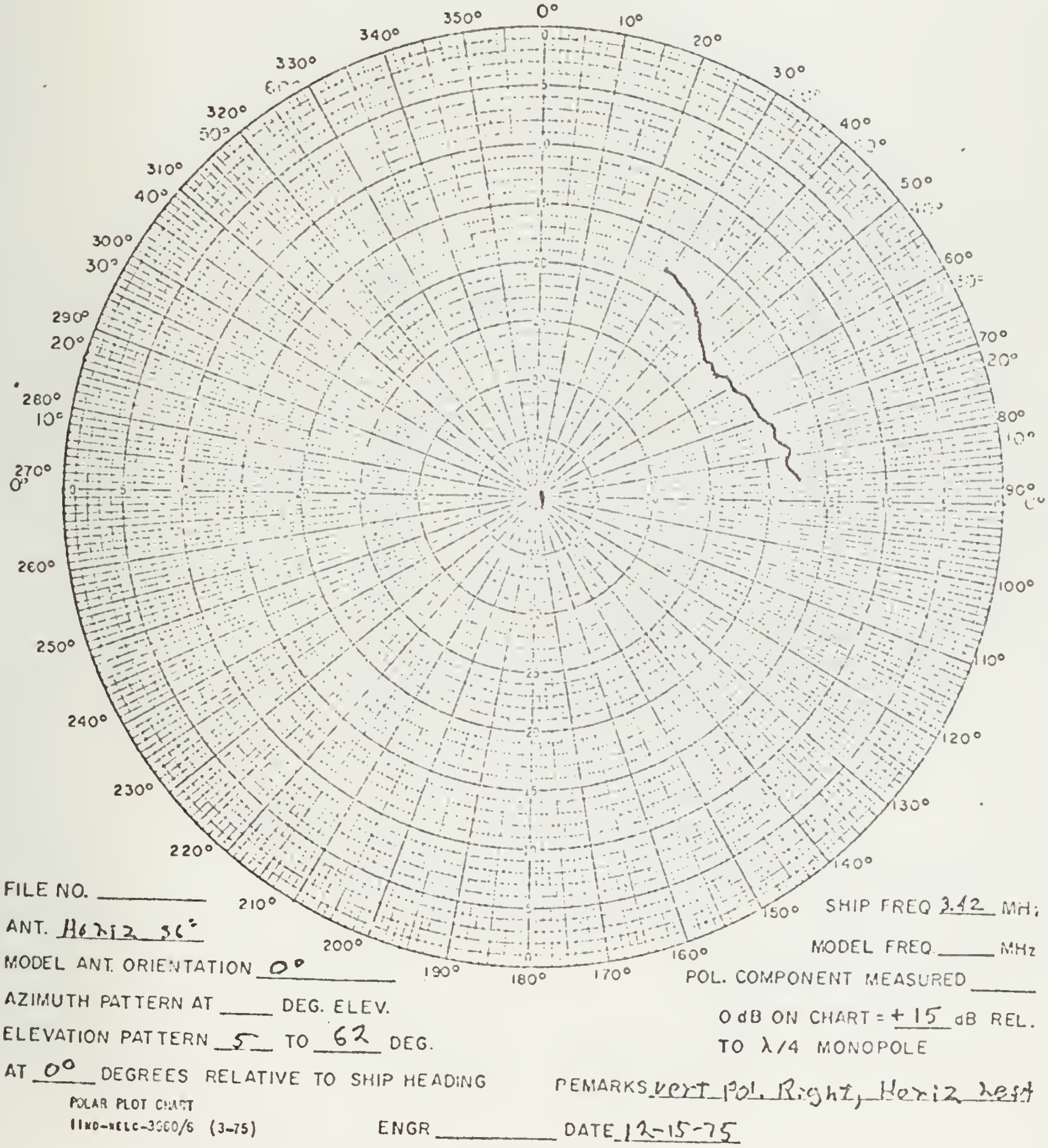


Figure 10

Dipole radiation at zero degrees relative to ship's heading, 3.42 MHZ

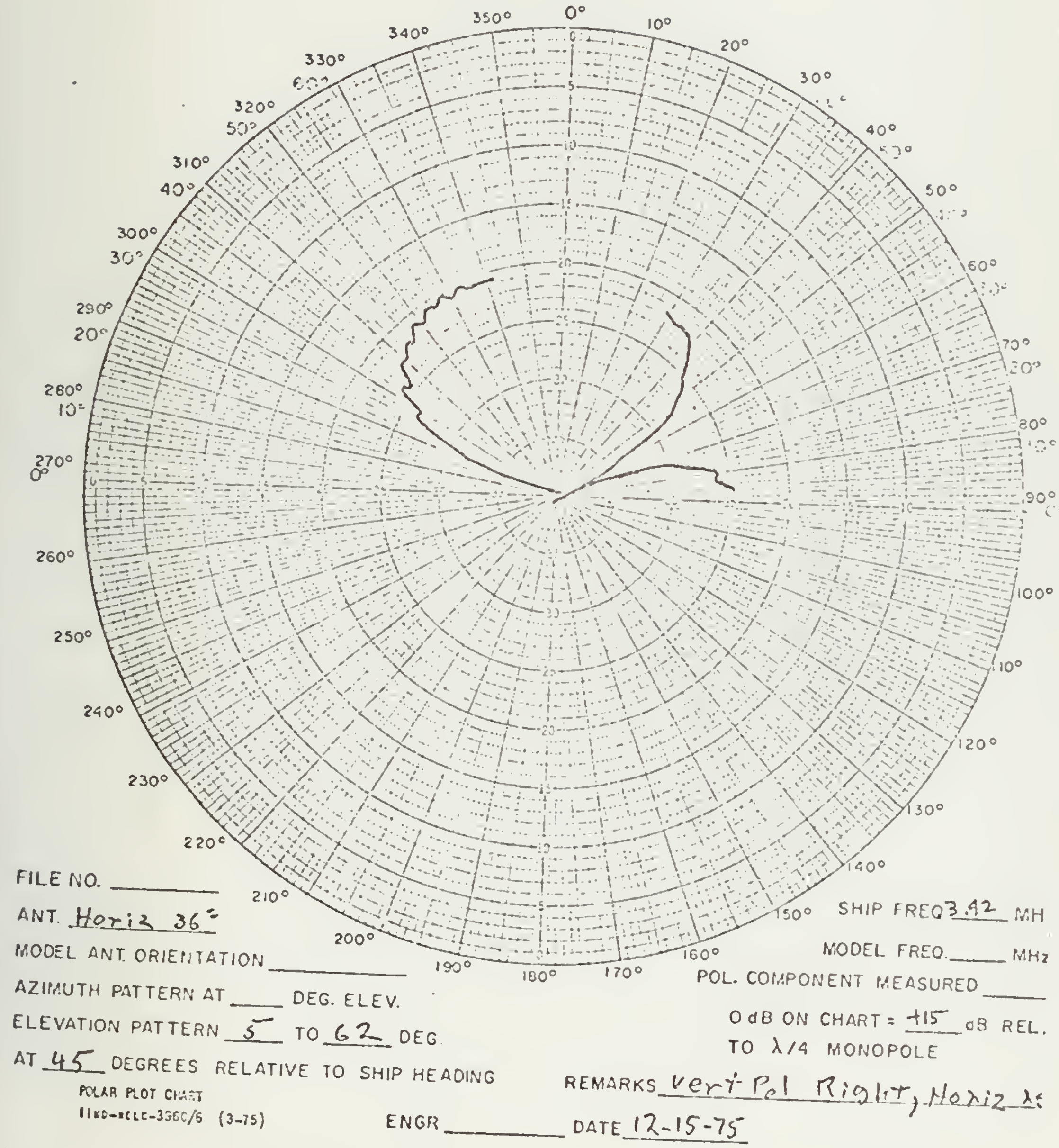


Figure 11

Dipole radiation at 45 degrees relative to ship's heading, 3.42 MHZ

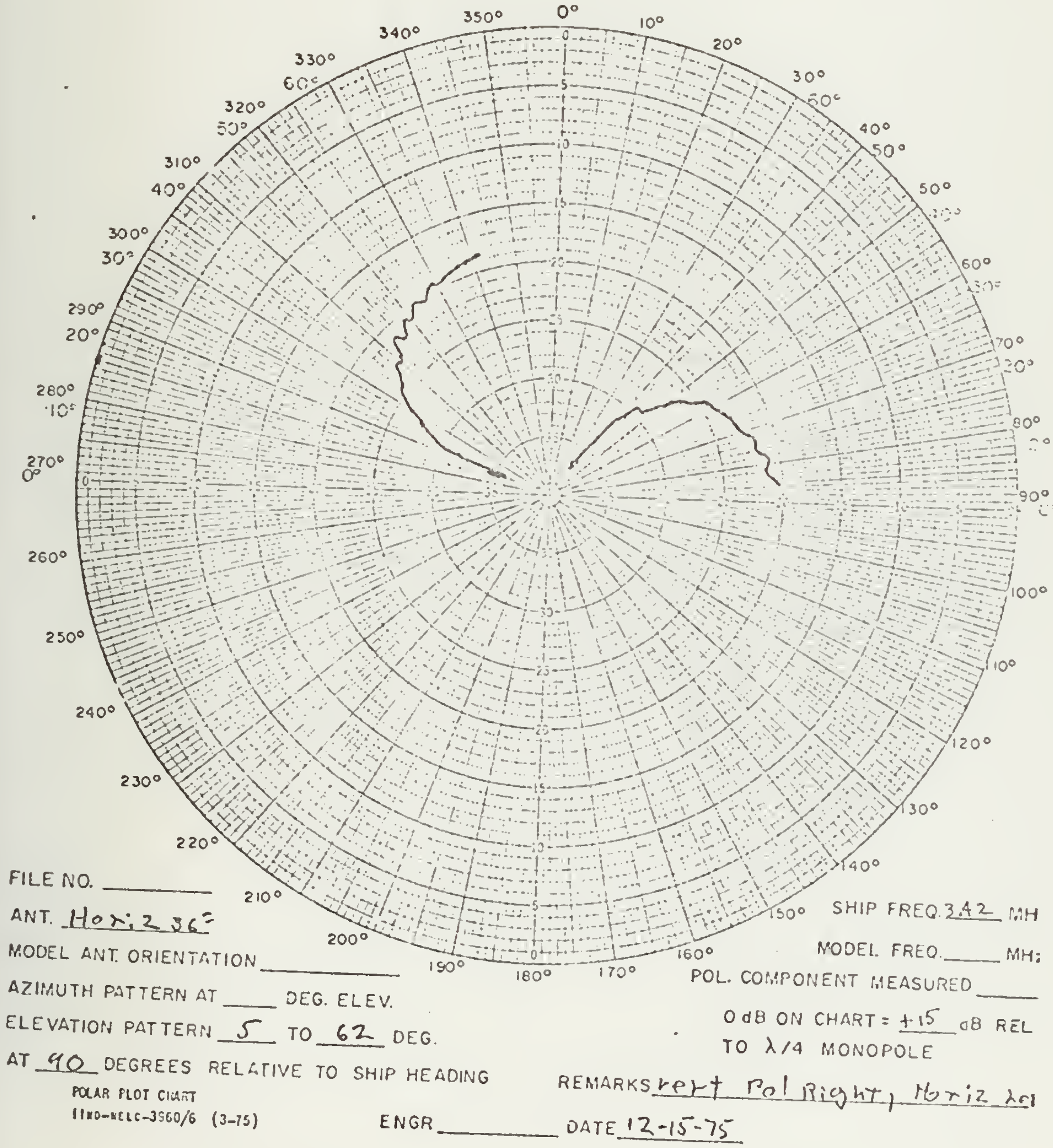


Figure 12

Dipole radiation at 90 degrees relative to ship's heading 3.42 degrees

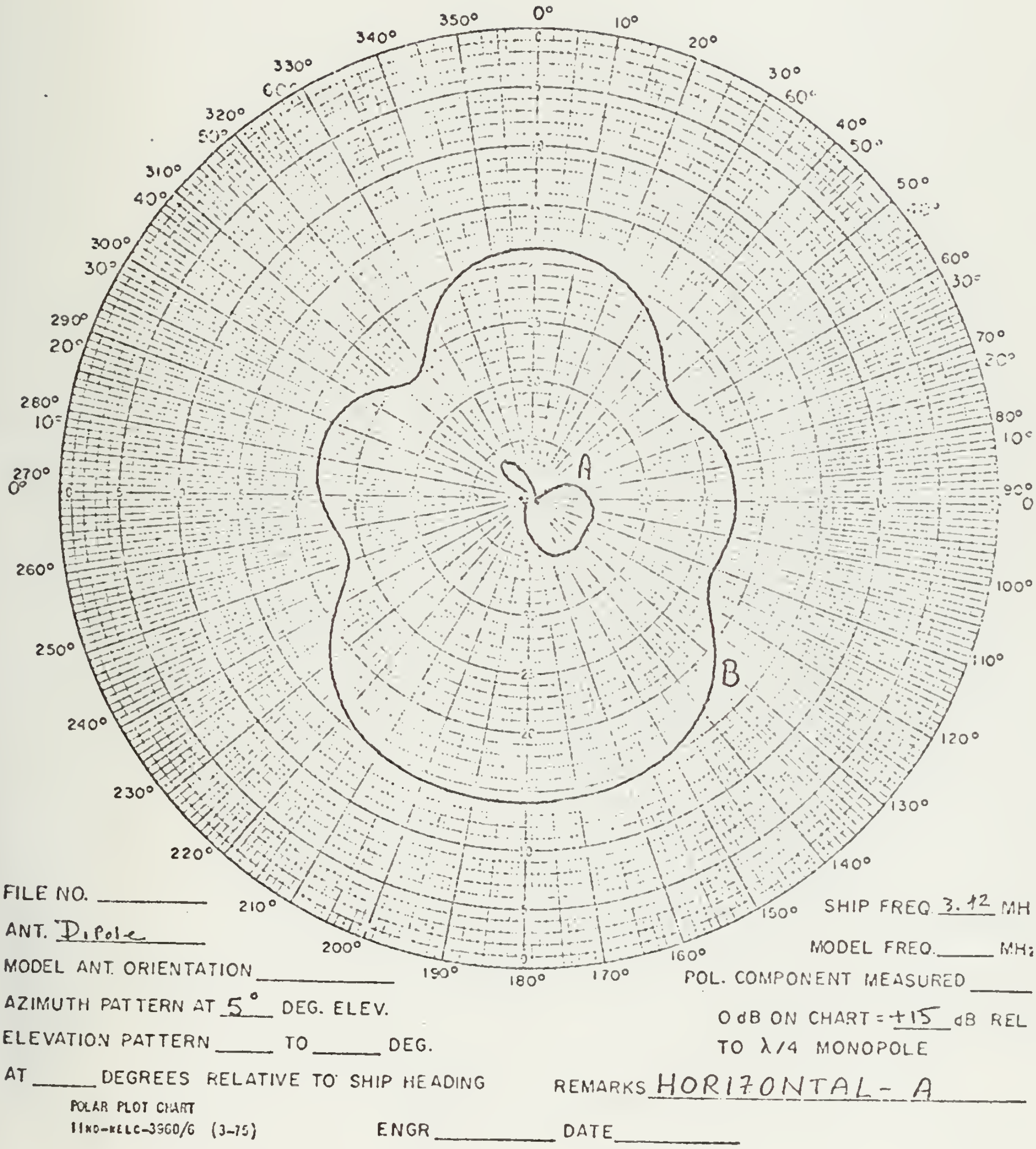


Figure 13

Dipole radiation at five degrees elevation, 3.42 MHZ

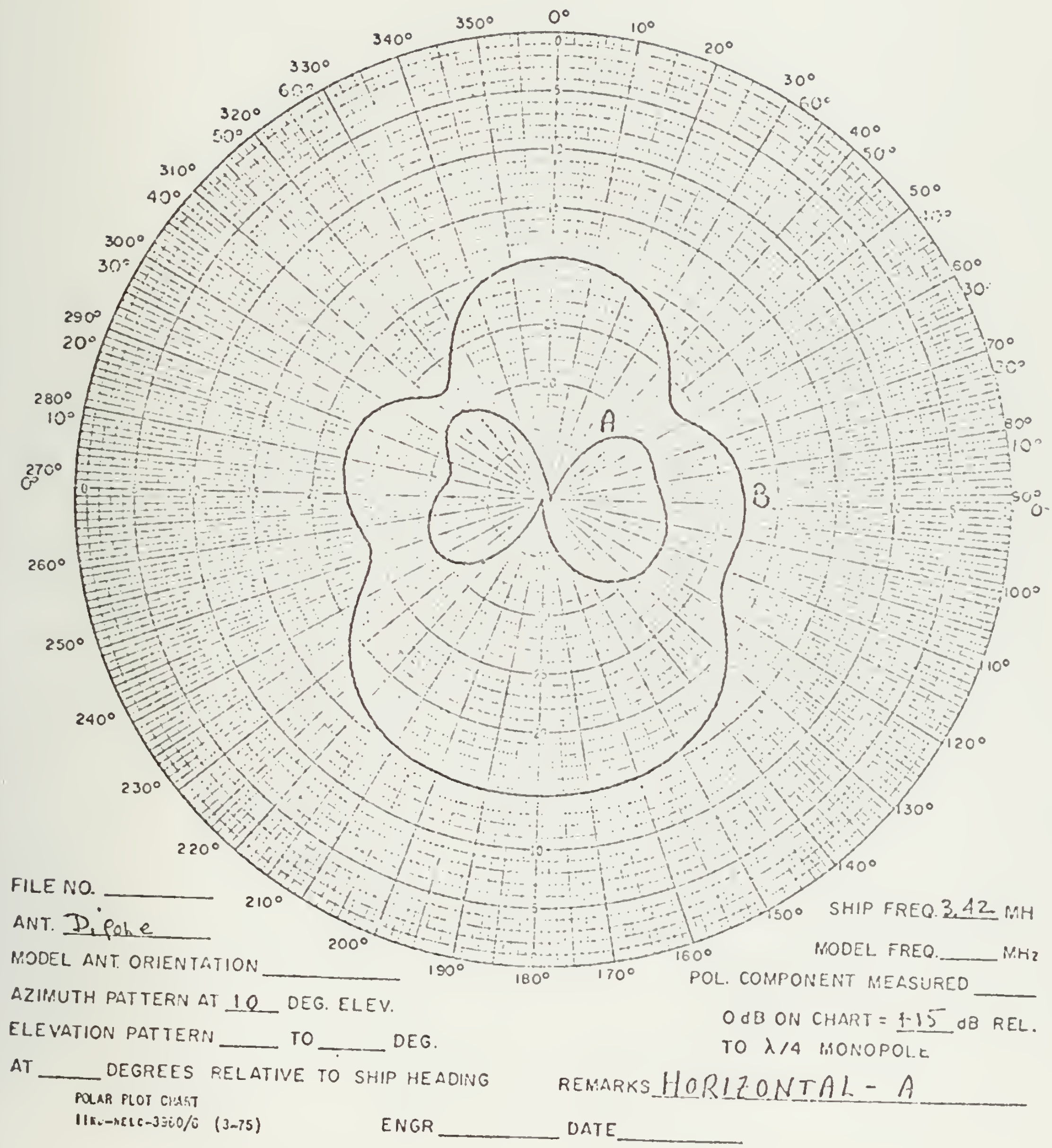


Figure 14

Dipole radiation at 10 degrees elevation, 3.42 MHZ

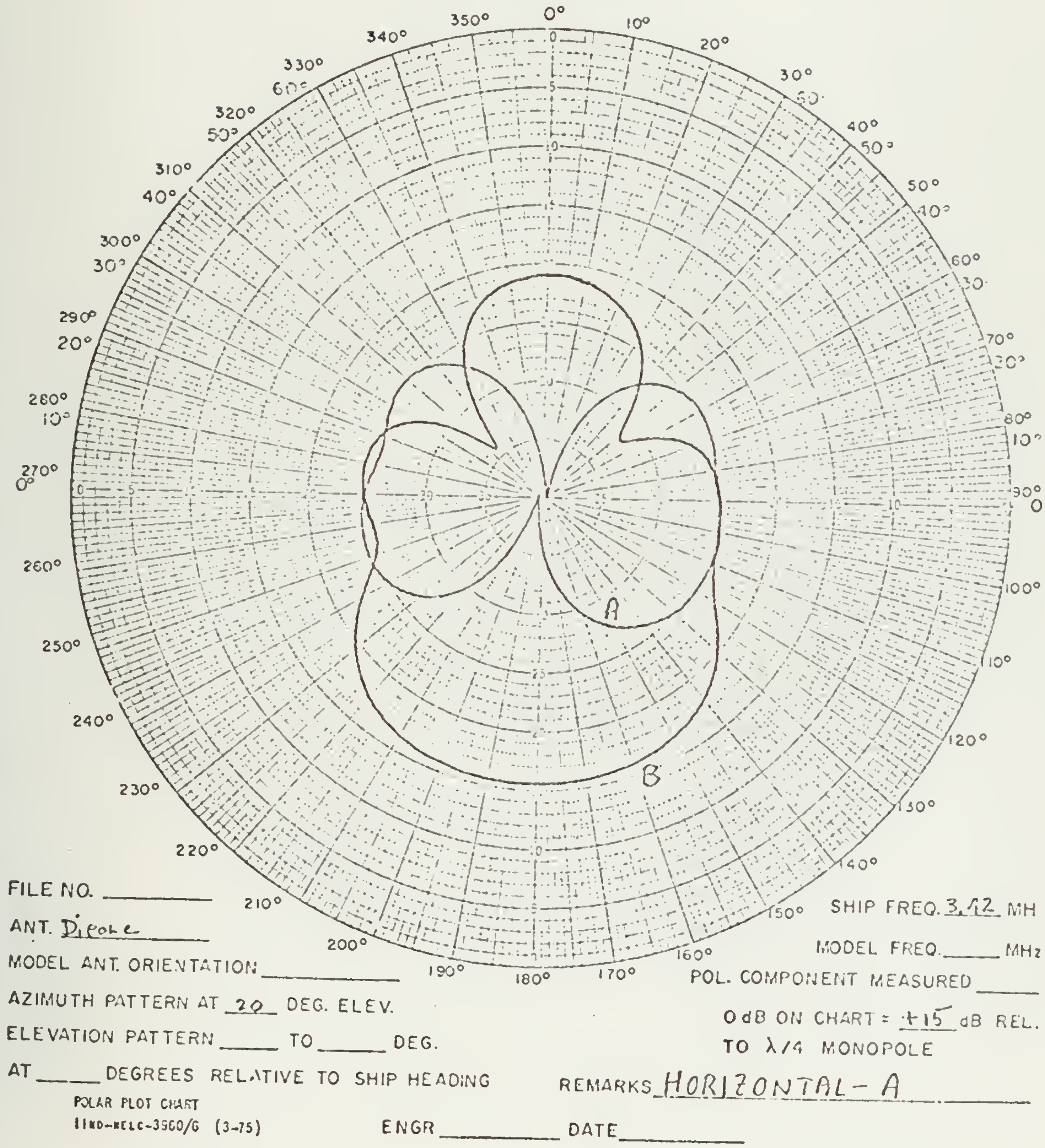


Figure 15

Dipole radiation at 20 degrees elevation, 3.42 MHZ

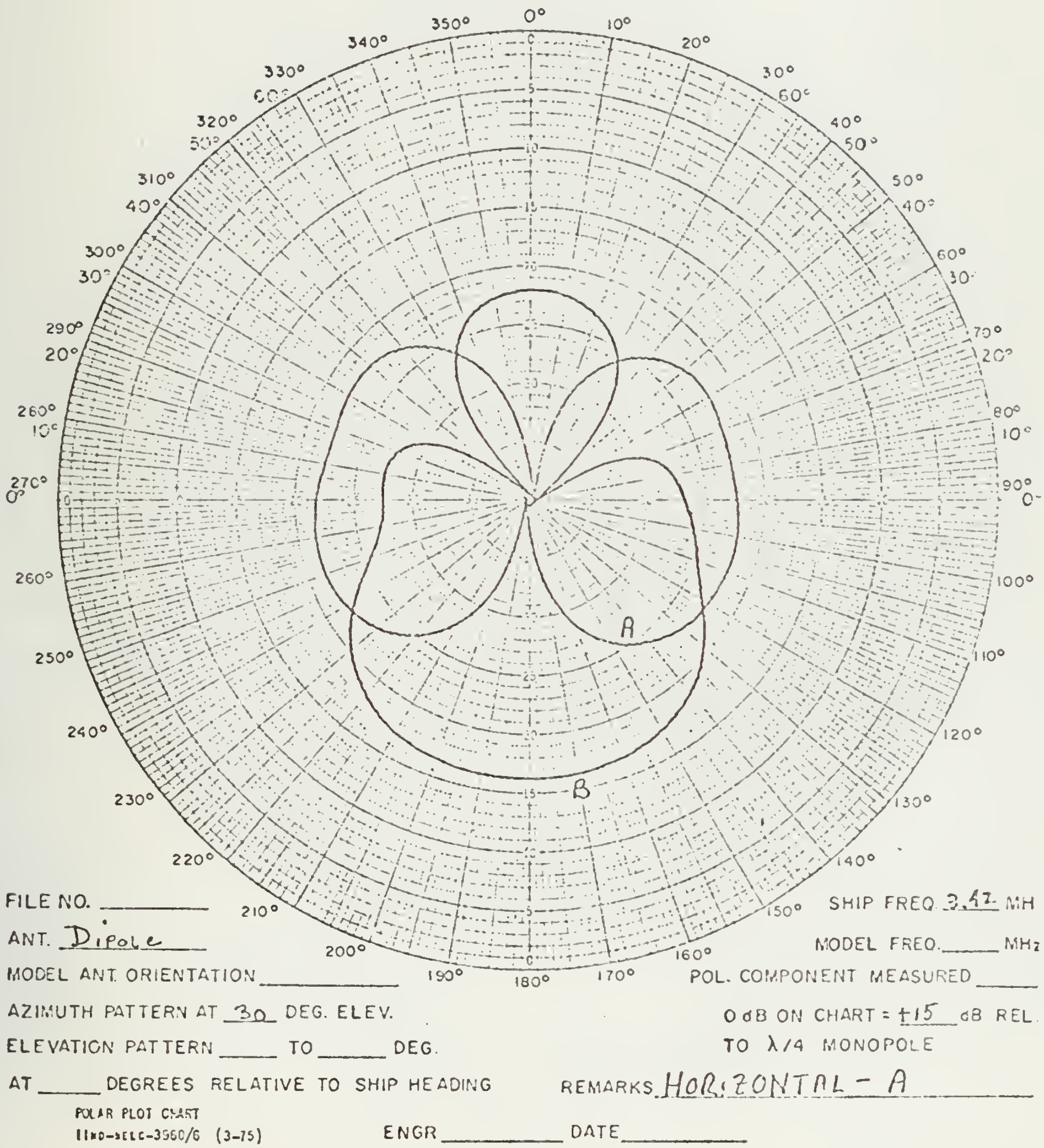


Figure 16

Dipole radiation at 30 degrees elevation, 3.42 MHZ

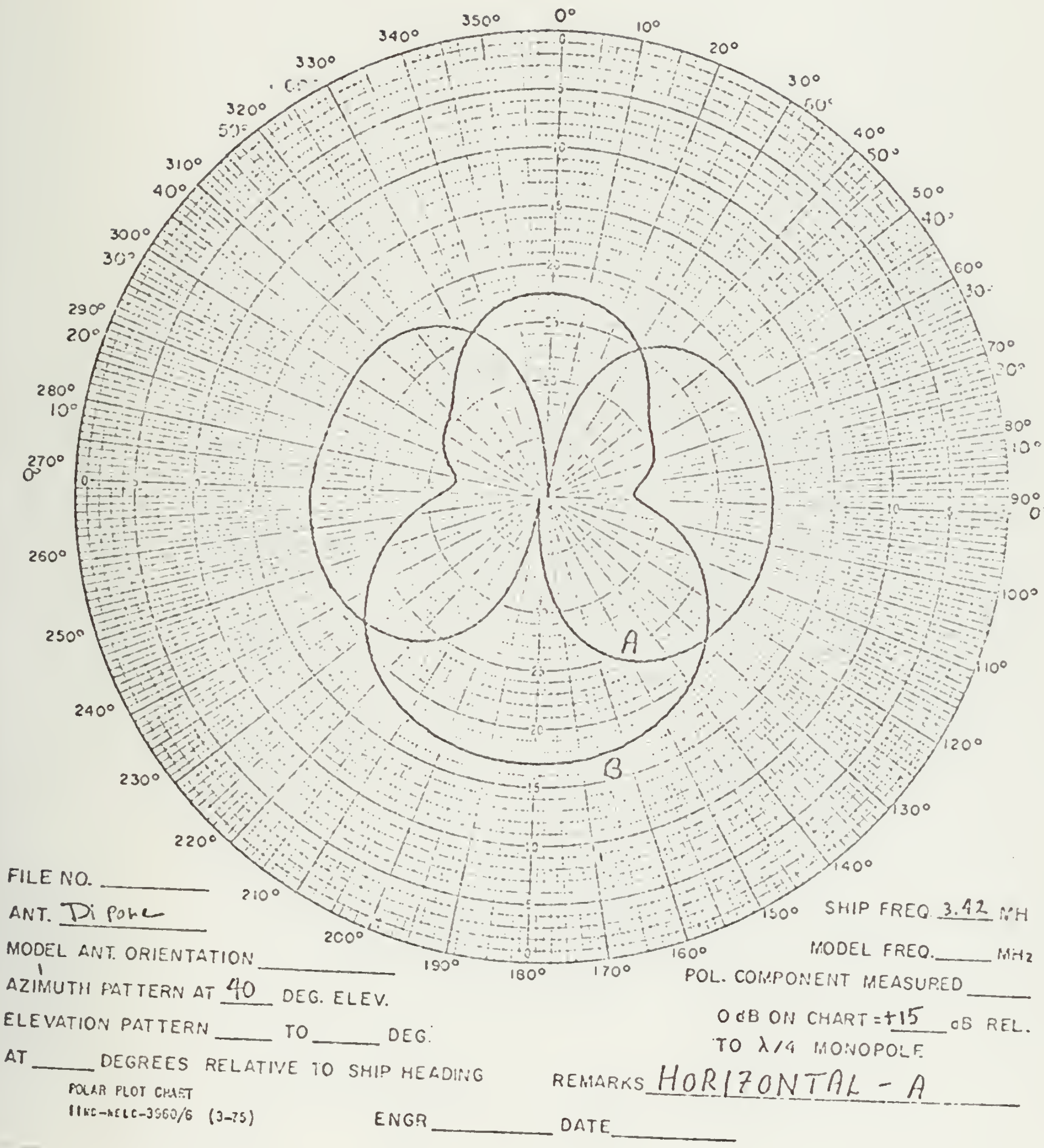


Figure 17

Dipole radiation at 40 degrees elevation, 3.42 MHZ

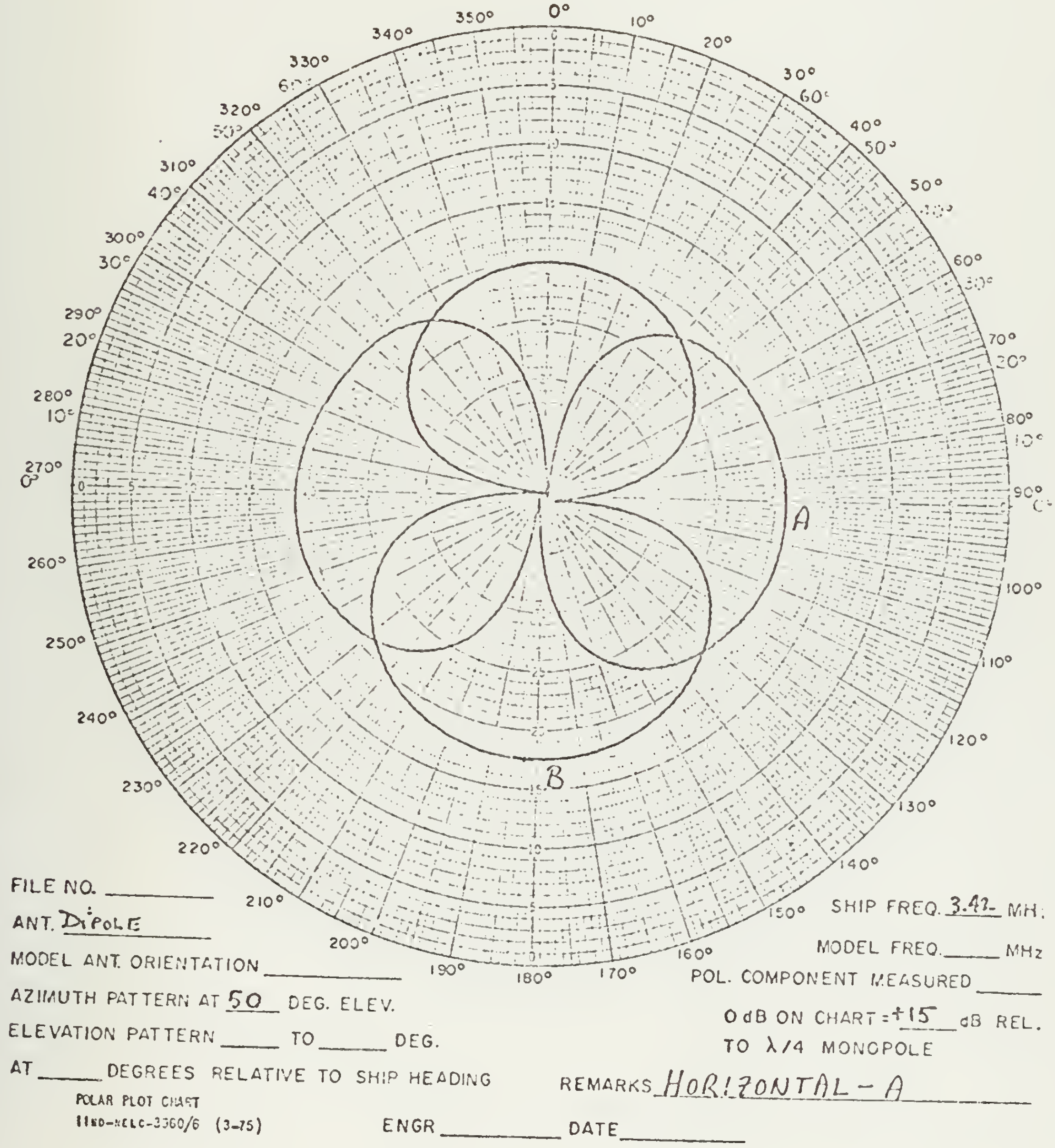


Figure 18

Dipole radiation at 50 degrees elevation, 3.42 MHZ

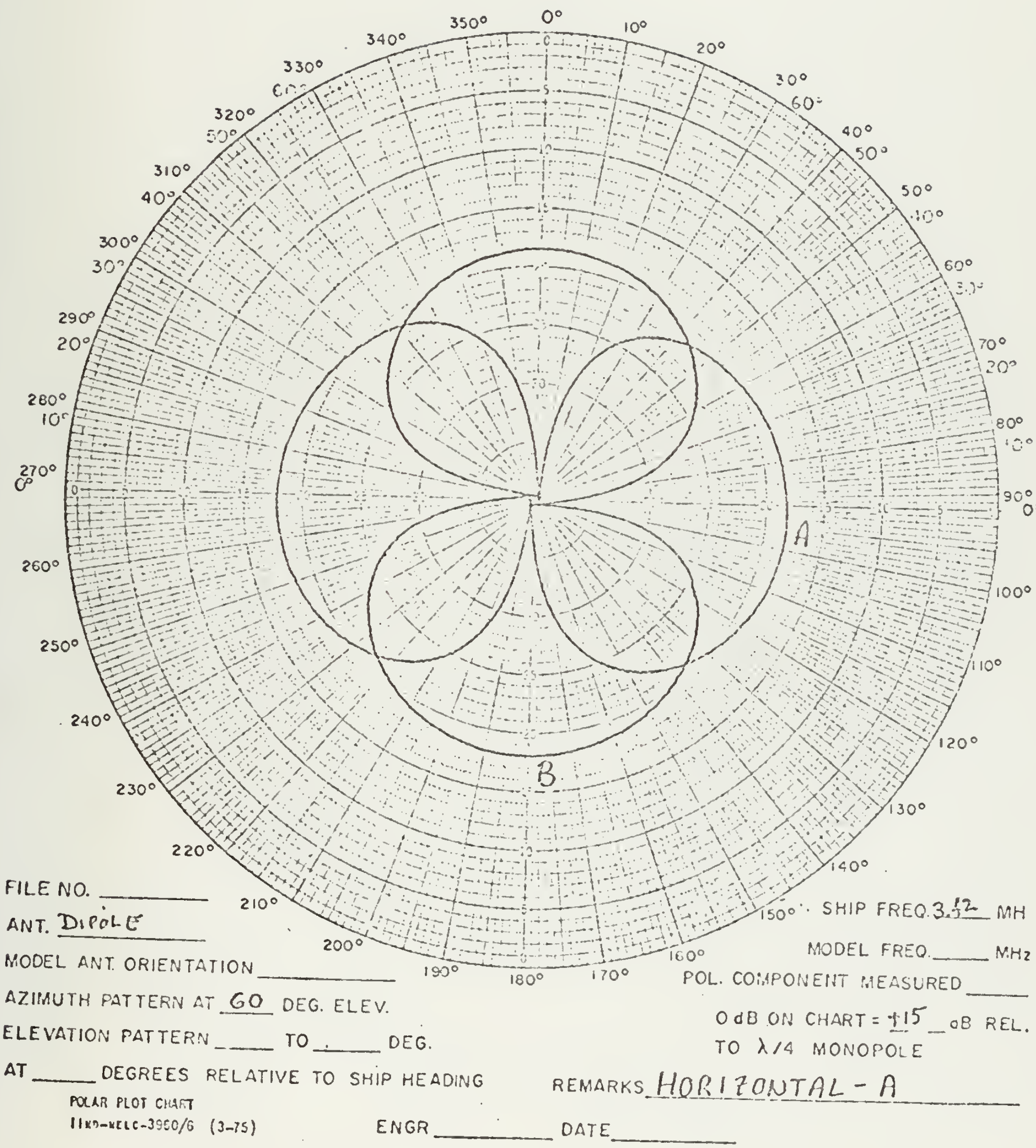


Figure 19

Dipole radiation at 60 degrees elevation, 3.42 MHZ

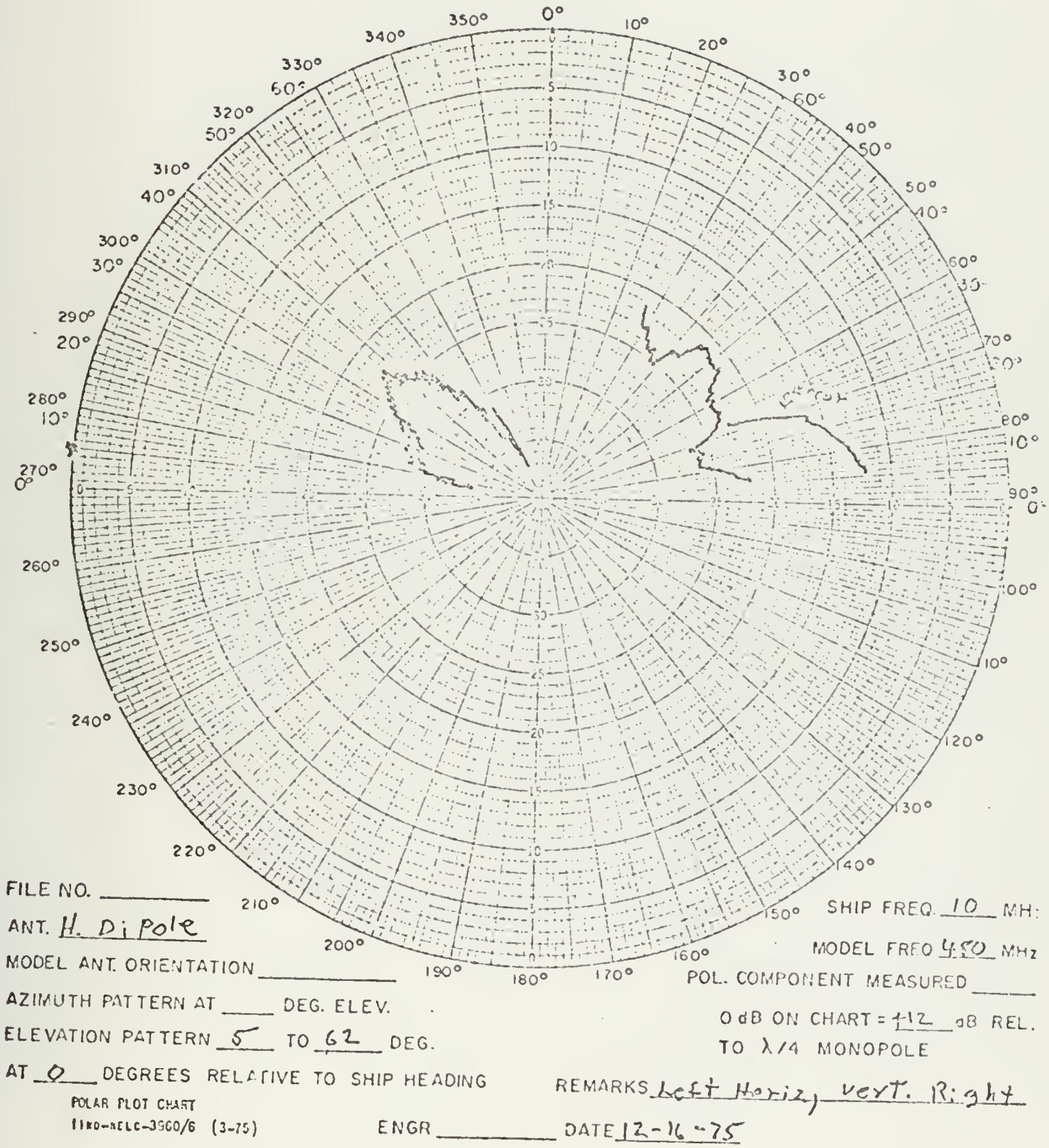


Figure 20

Dipole radiation at zero degrees relative to ship's heading, 10 MHZ

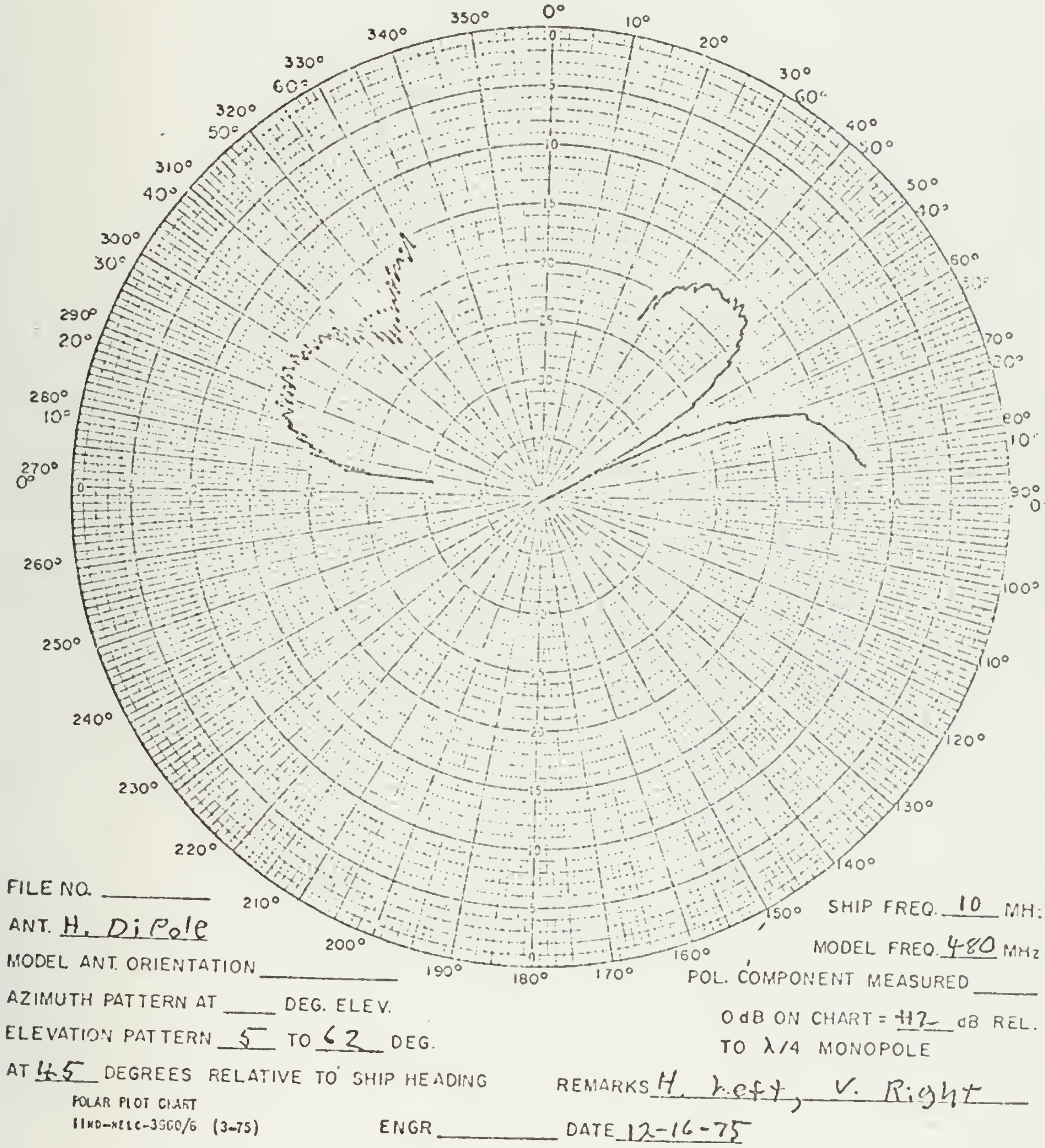


Figure 21

Dipole radiation at 45 degrees relative to ship's heading, 10 MHZ

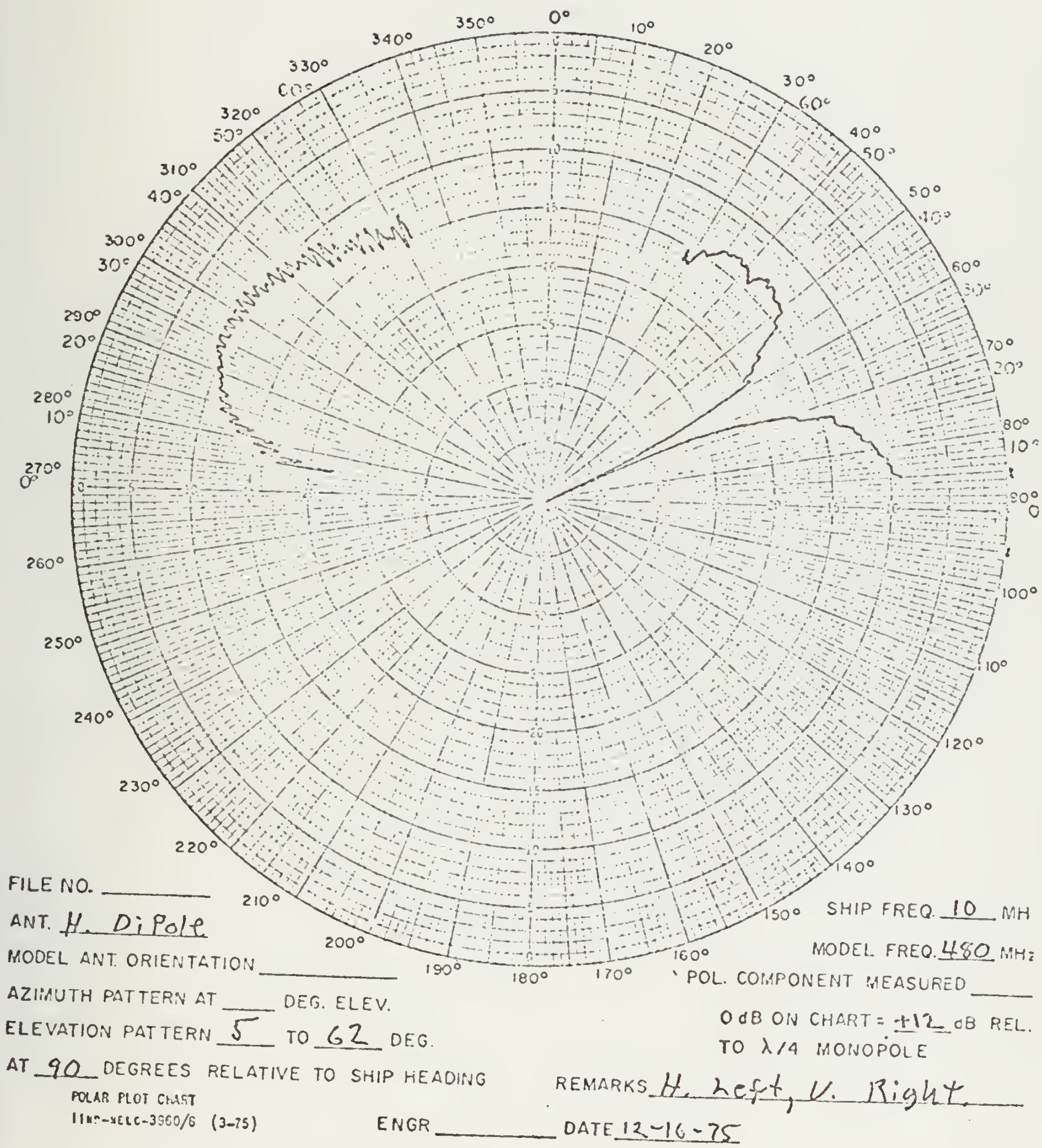


Figure 22

Dipole radiation at 90 degrees relative to ship's heading, 10 MHZ

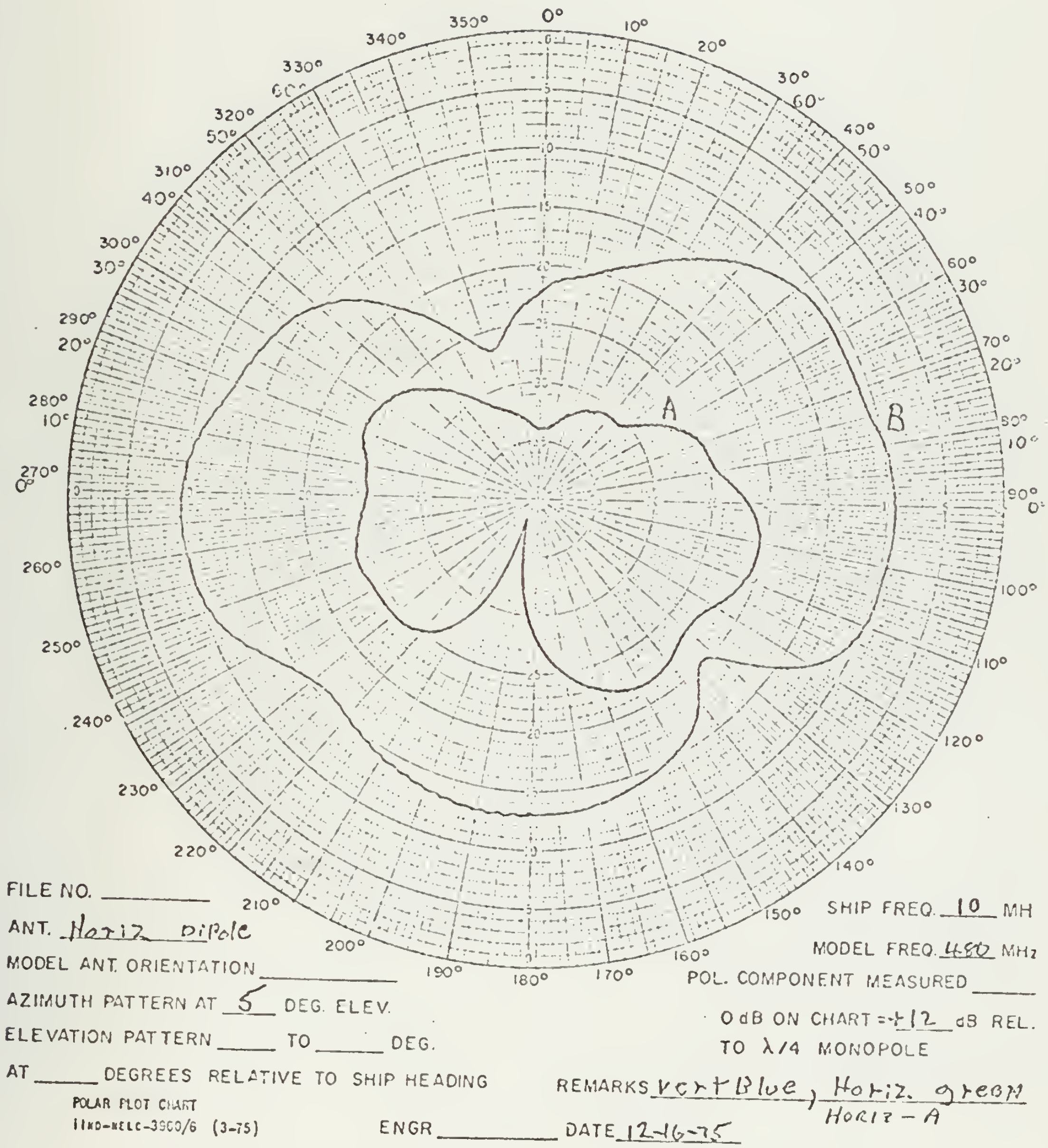


Figure 23

Dipole radiation at five degrees elevation, 10 MHZ

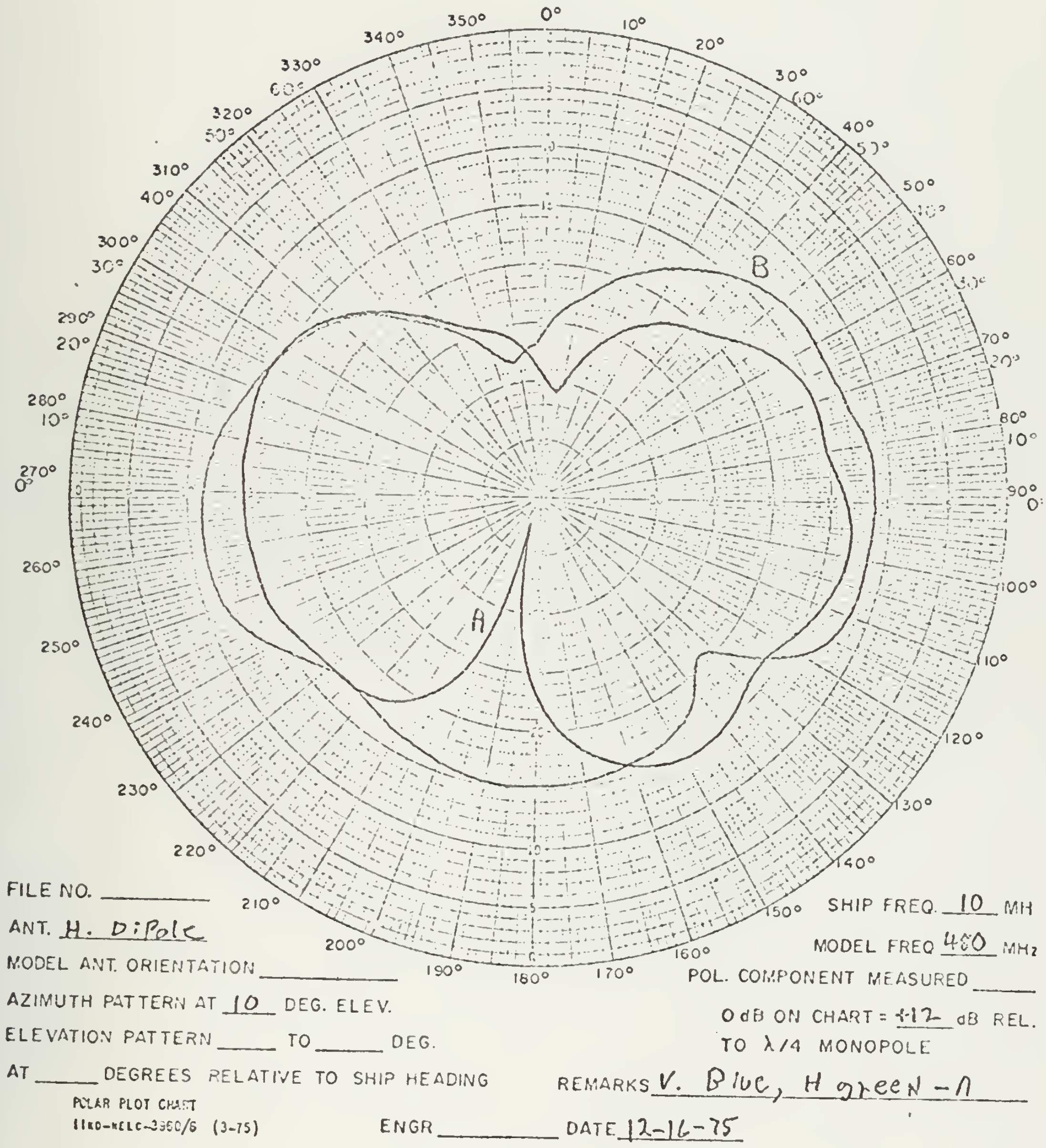


Figure 24

Dipole radiation at 10 degrees elevation, 10 MHZ

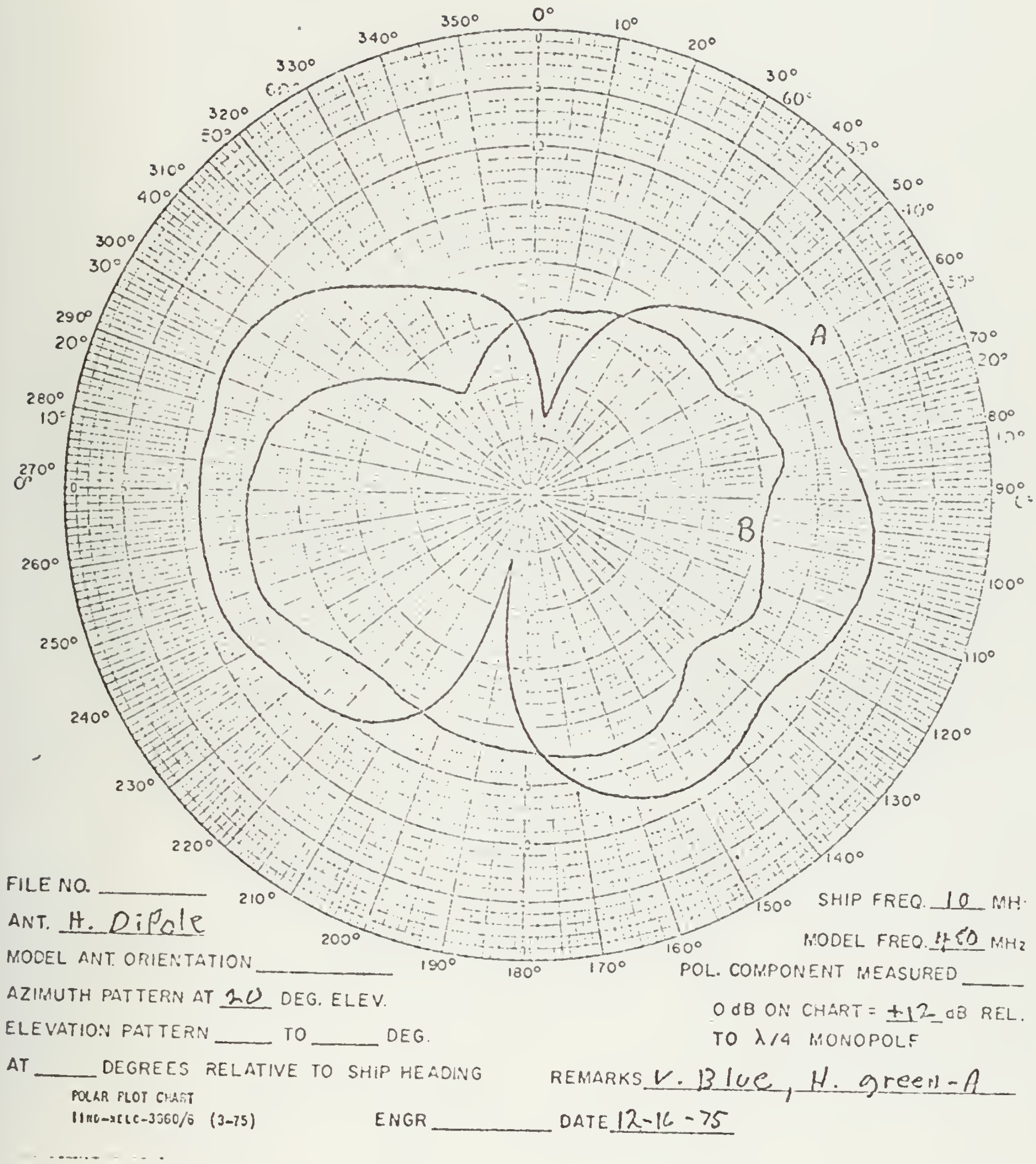


Figure 25

Dipole radiation at 20 degrees elevation, 10 MHZ

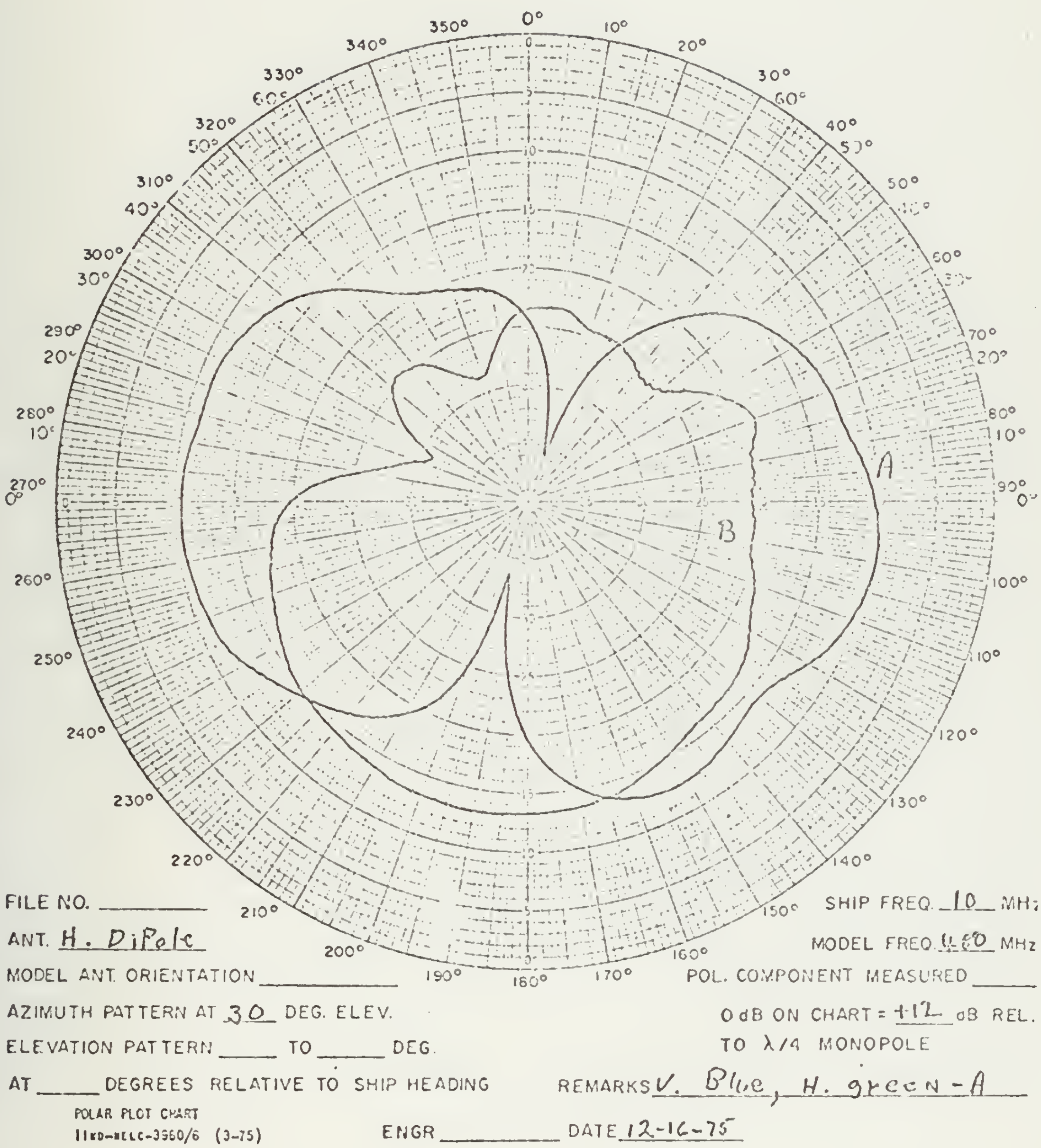


Figure 26

Dipole radiation at 30 degrees elevation, 10 MHZ

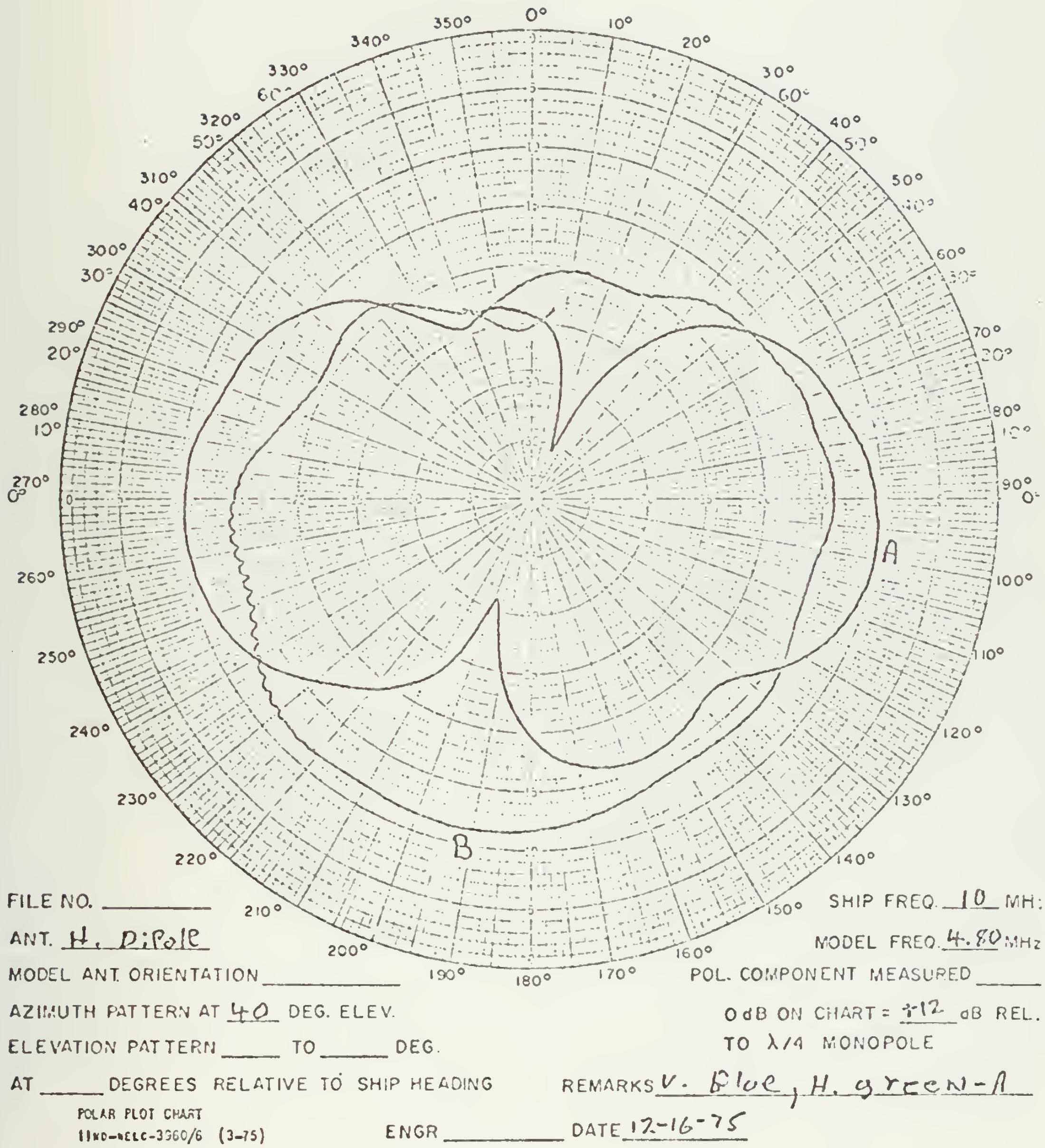


Figure 27

Dipole radiation at 40 degrees elevation, 10 MHZ

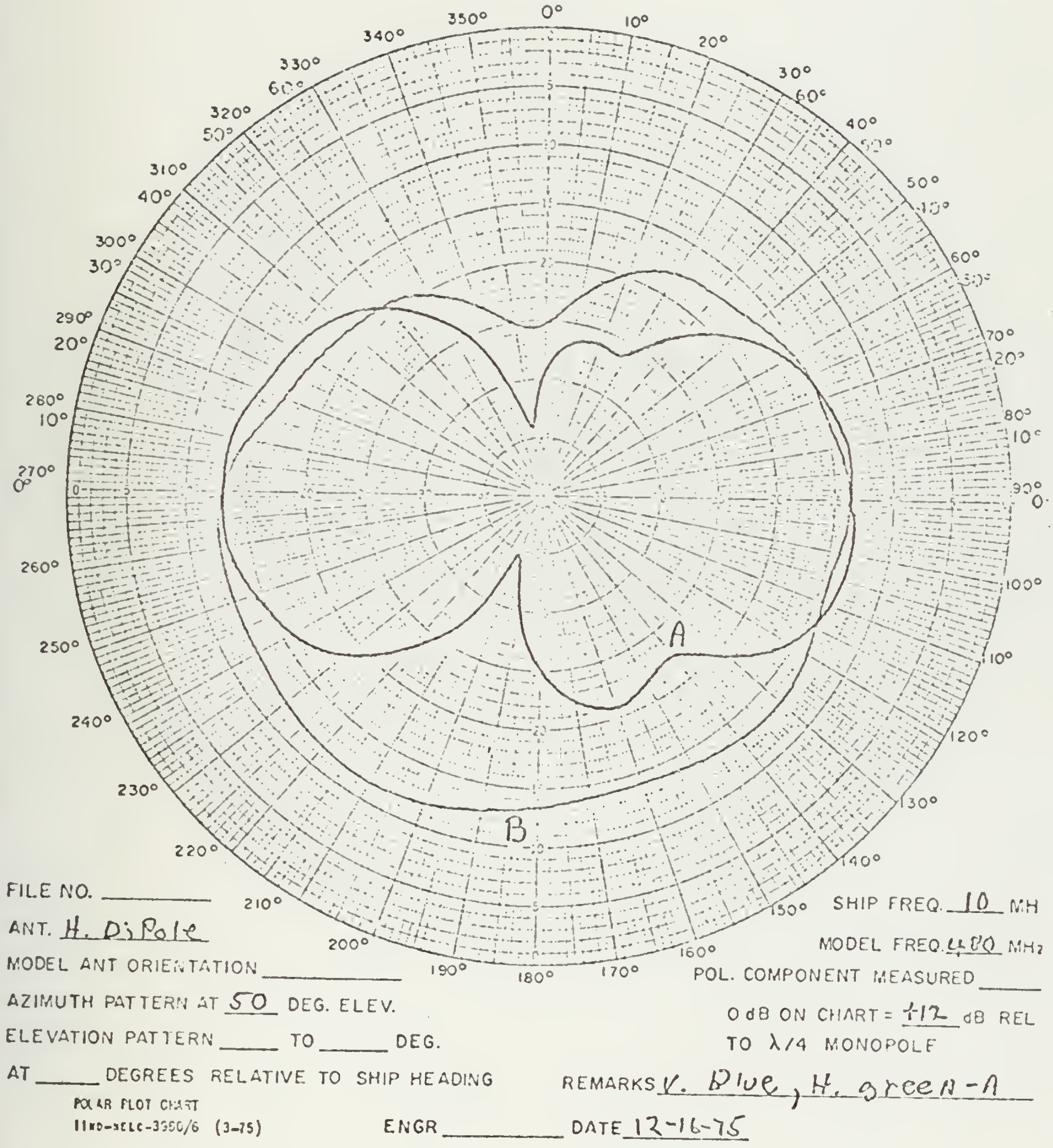


Figure 28

Dipole radiation at 50 degrees elevation, 10 MHZ

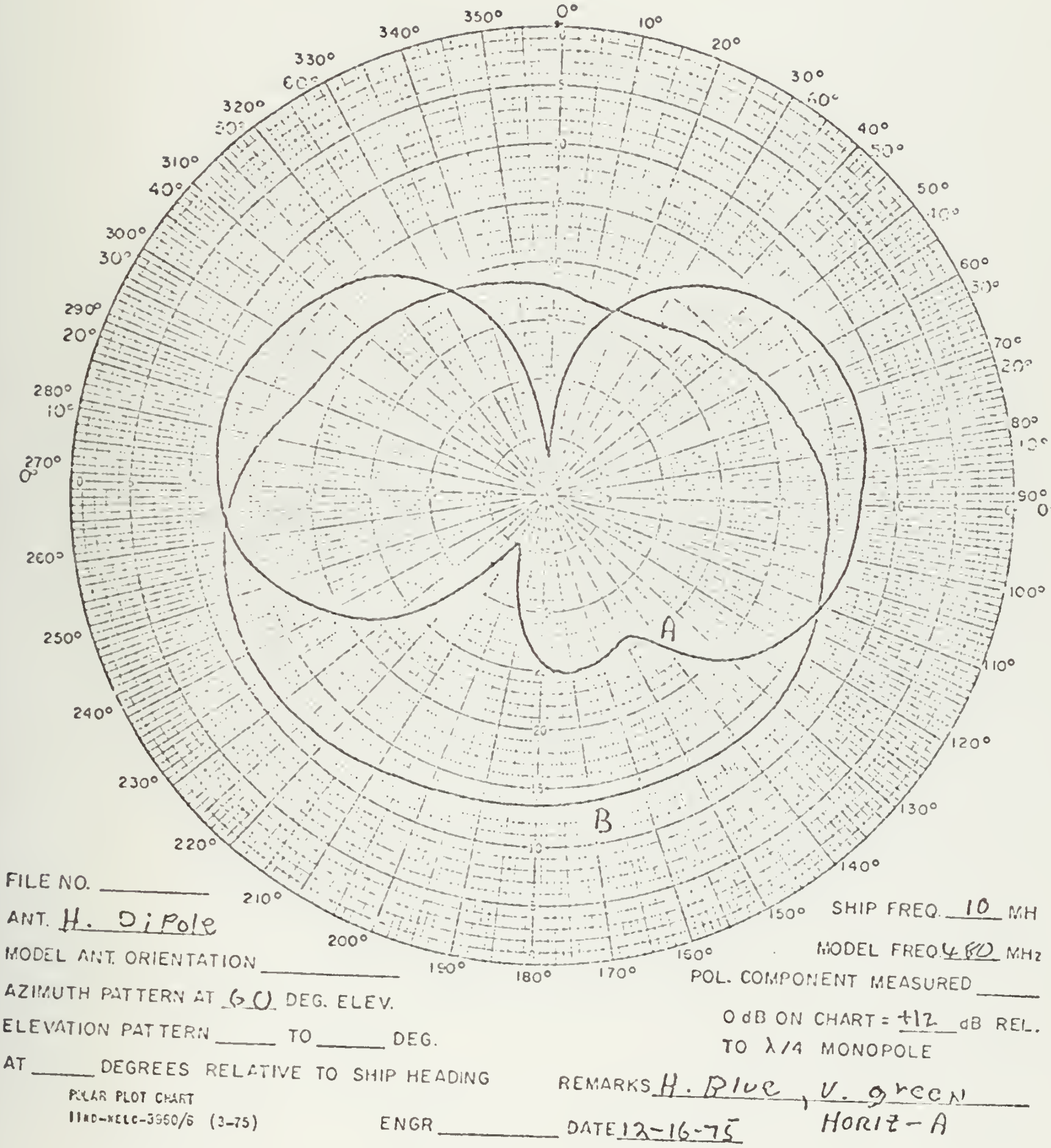


Figure 29

Dipole radiation at 60 degrees elevation, 10 MHZ

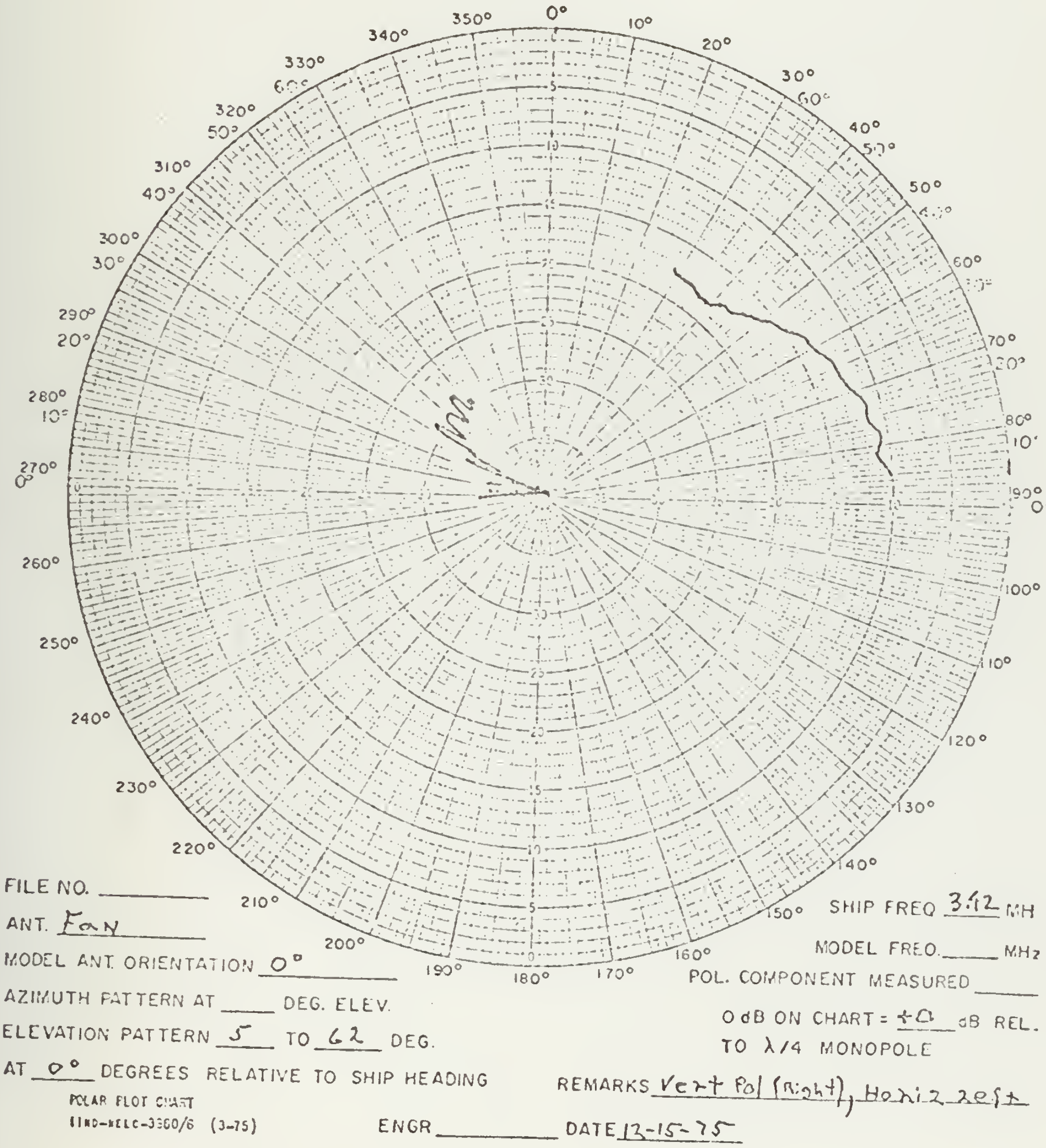


Figure 30

Fan radiation at zero degrees relative to ship's heading, 3.42 MHZ

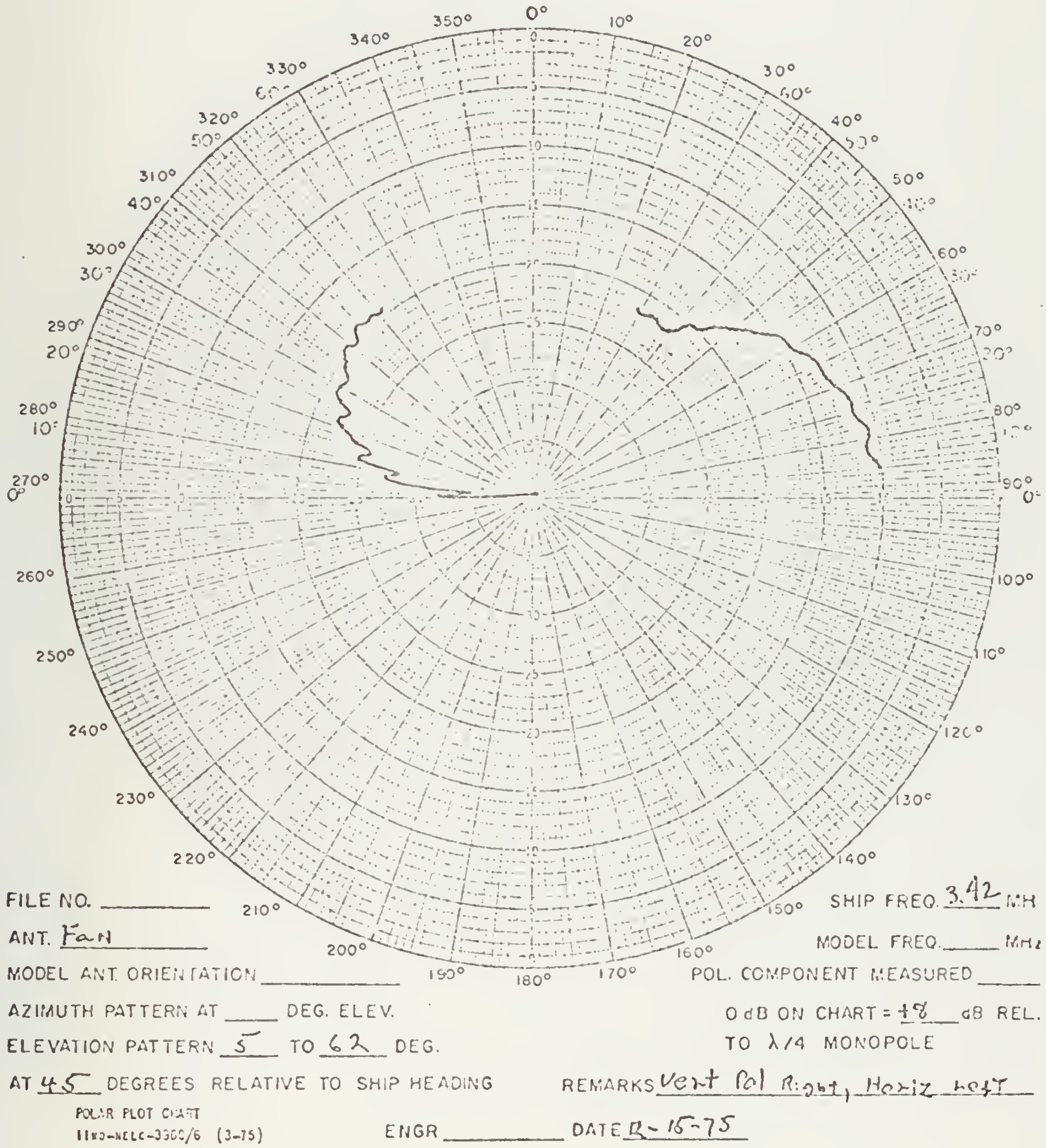


Figure 31

Fan radiation at 45 degrees relative to ship's heading, 3.42 MHZ

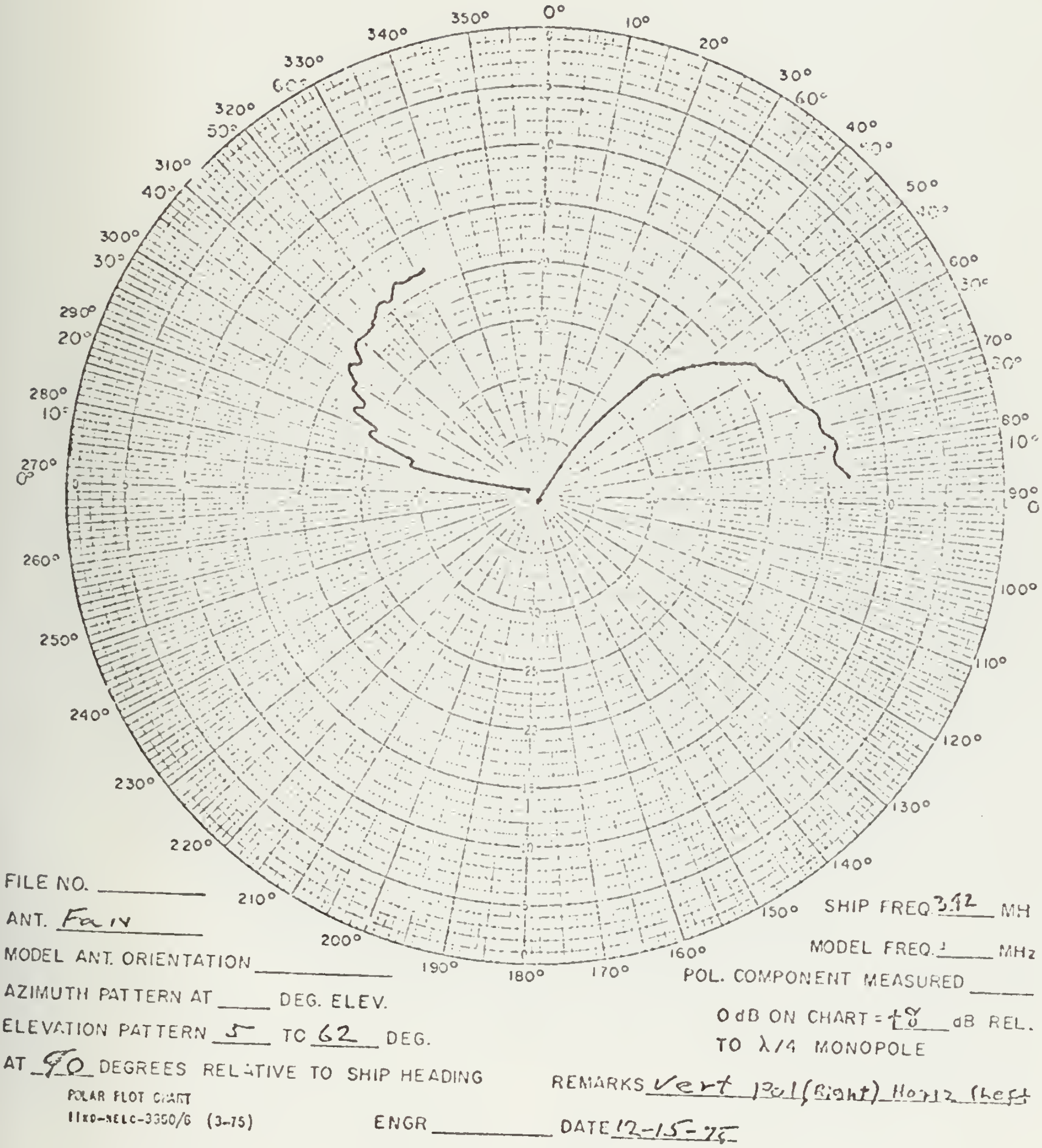


Figure 32

Fan radiation at 90 degrees relative to ship's heading, 3.42 MHZ

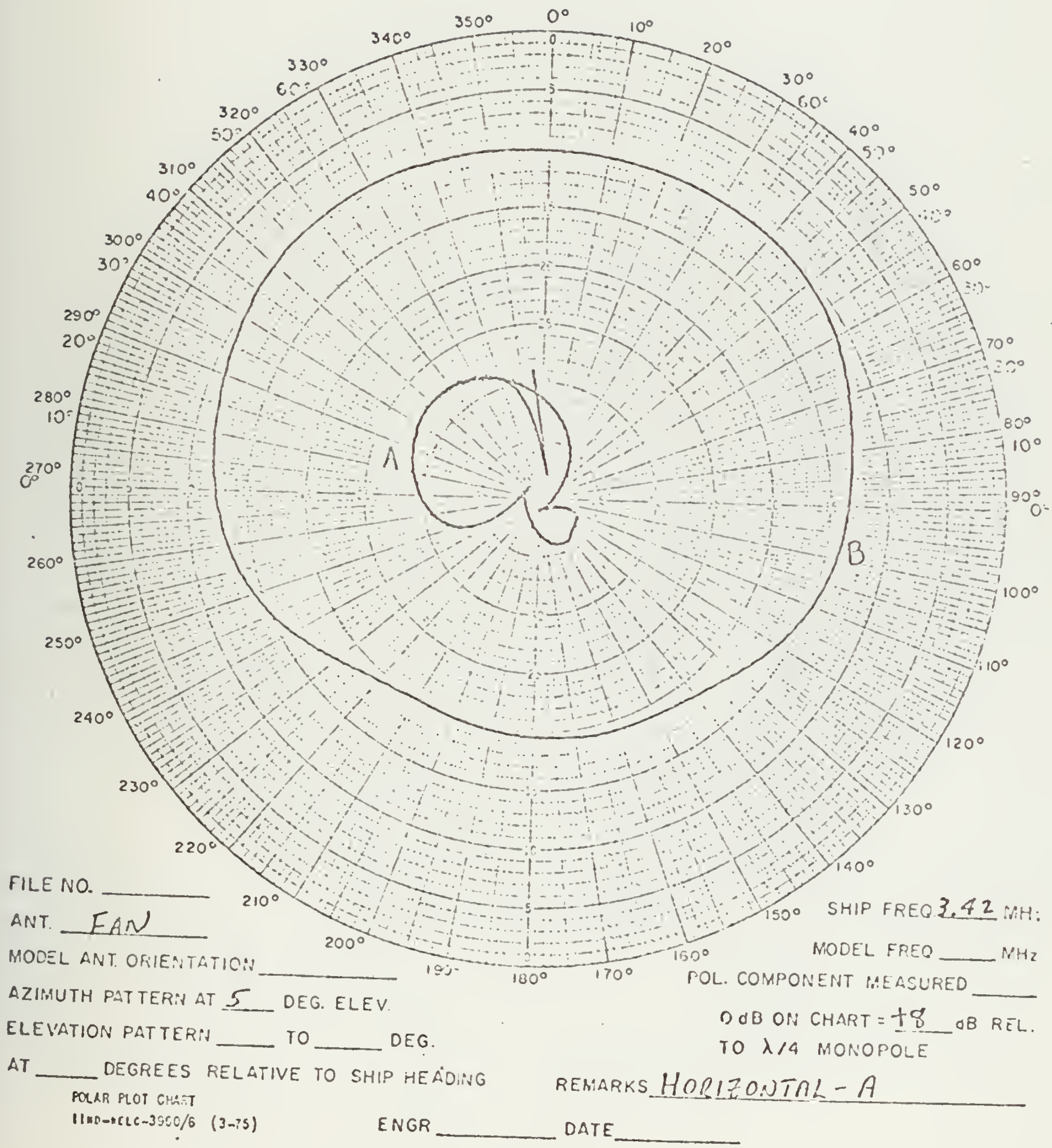


Figure 33

Fan radiation at five degrees elevation, 3.42 MHZ

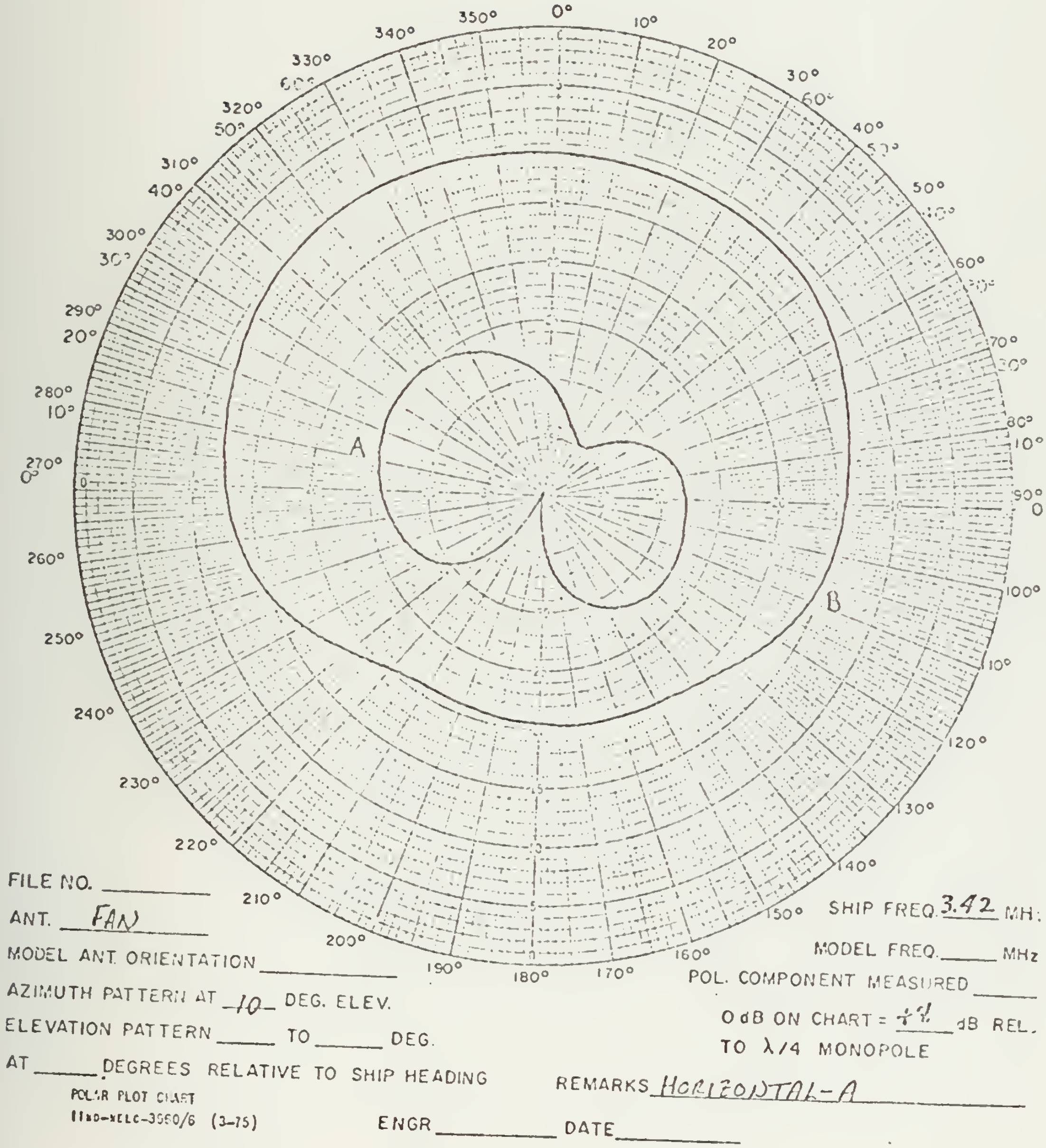


Figure 34

Fan radiation at 10 degrees elevation, 3.42 MHZ

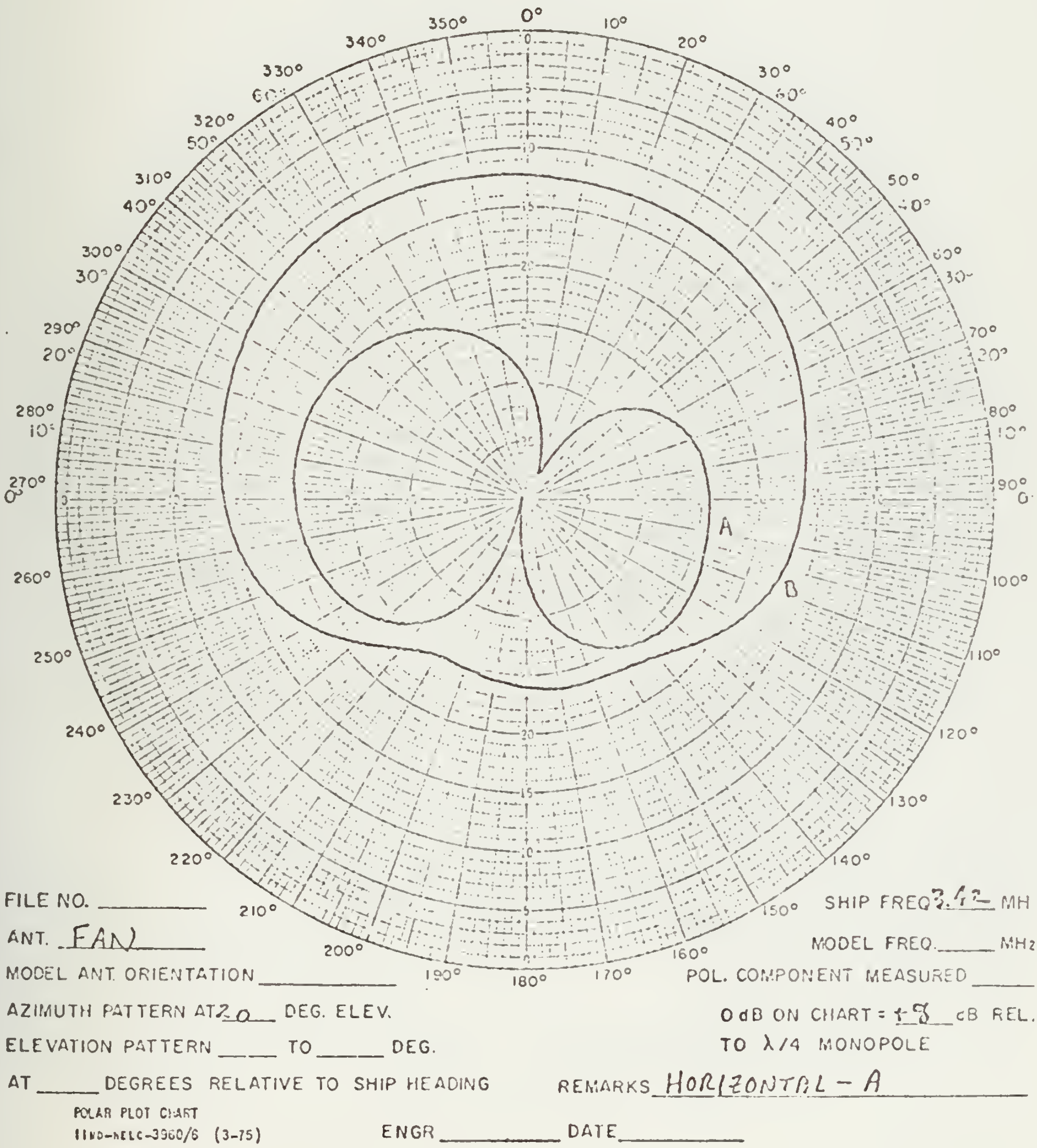


Figure 35

Fan radiation at 20 degrees elevation, 3.42 MHZ

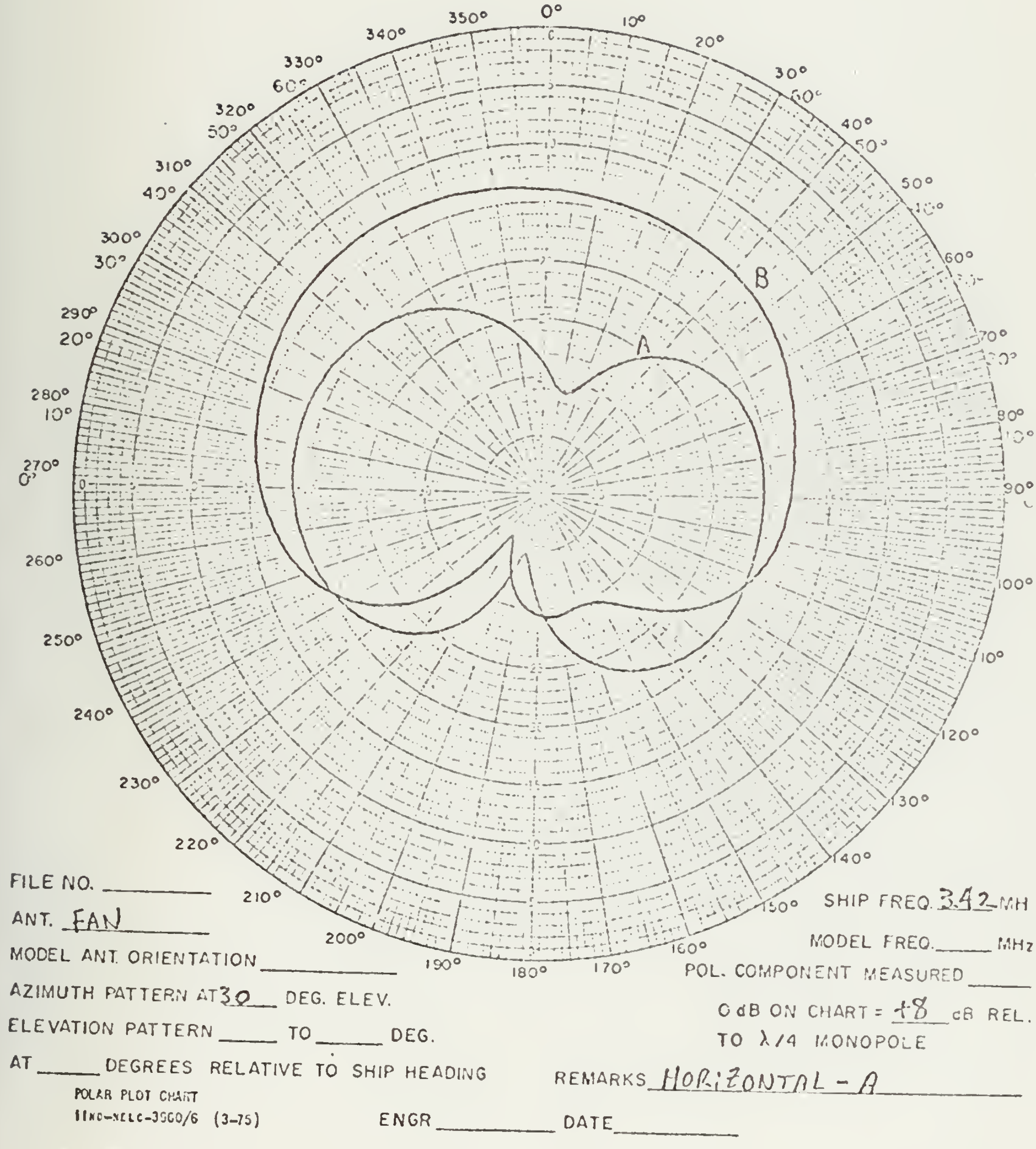


Figure 36

Fan radiation at 30 degrees elevation, 3.42 MHZ

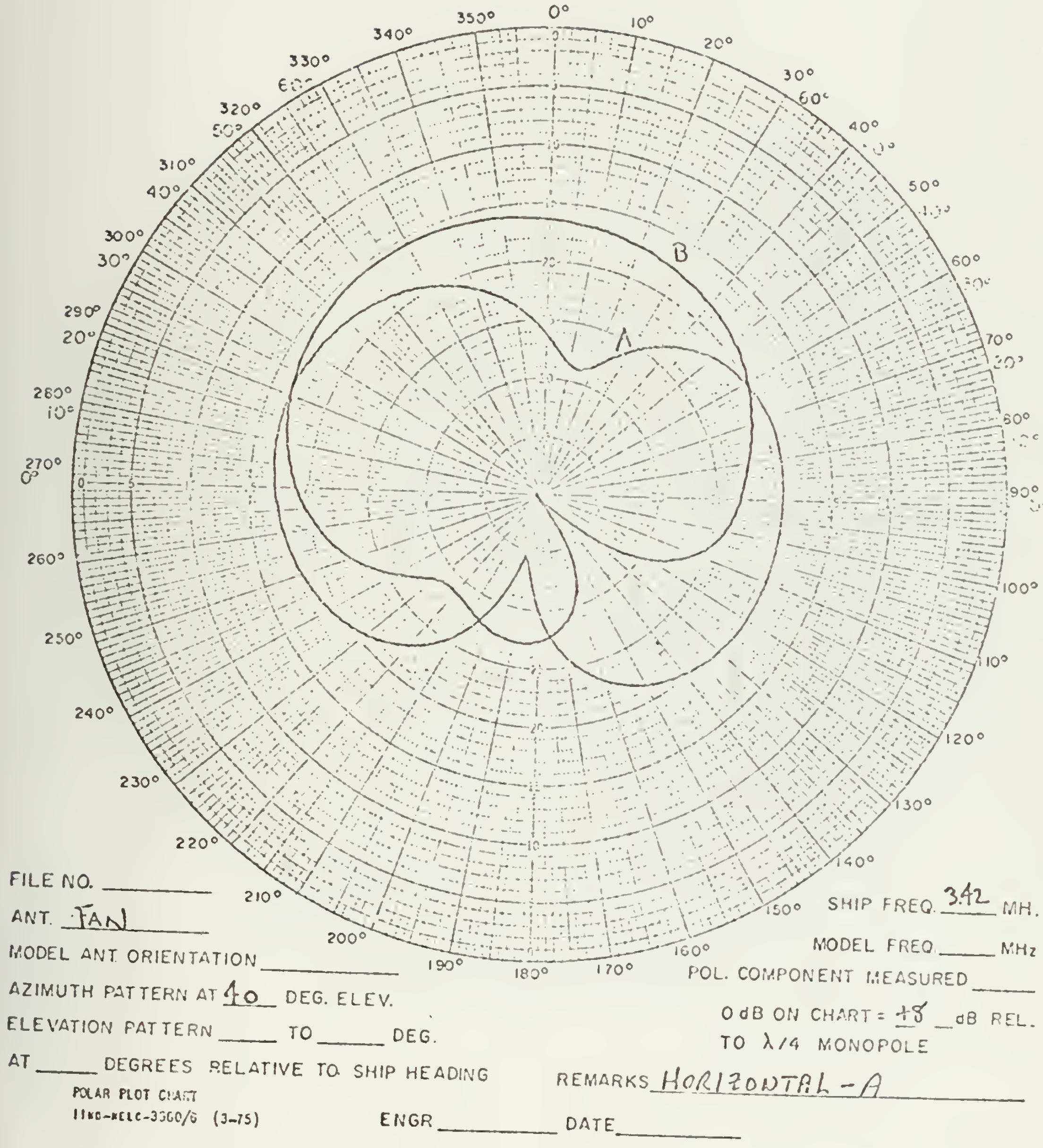


Figure 37

Fan radiation at 40 degrees elevation, 3.42 MHZ

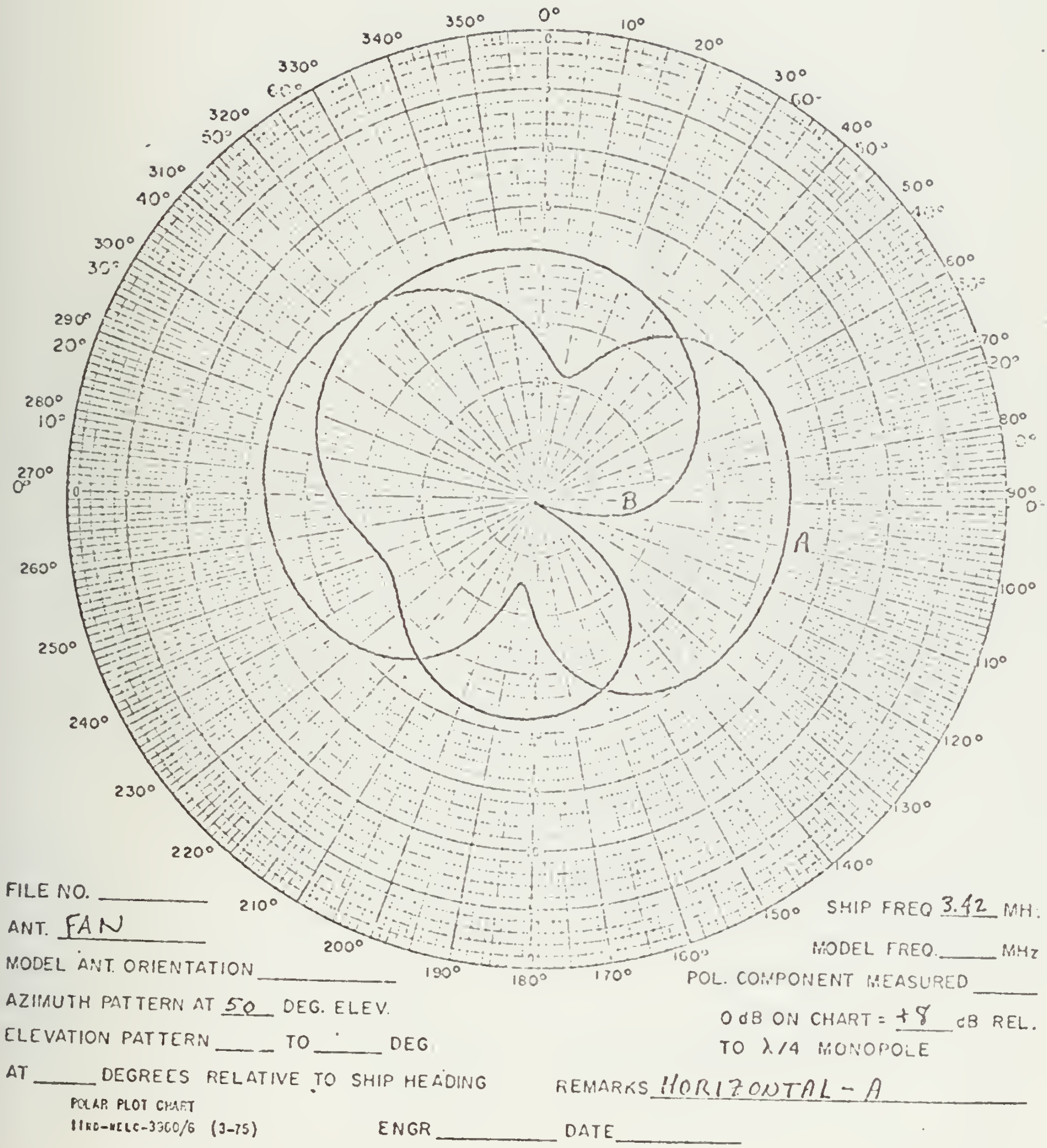


Figure 38

Fan radiation at 50 degrees elevation, 3.42 MHZ

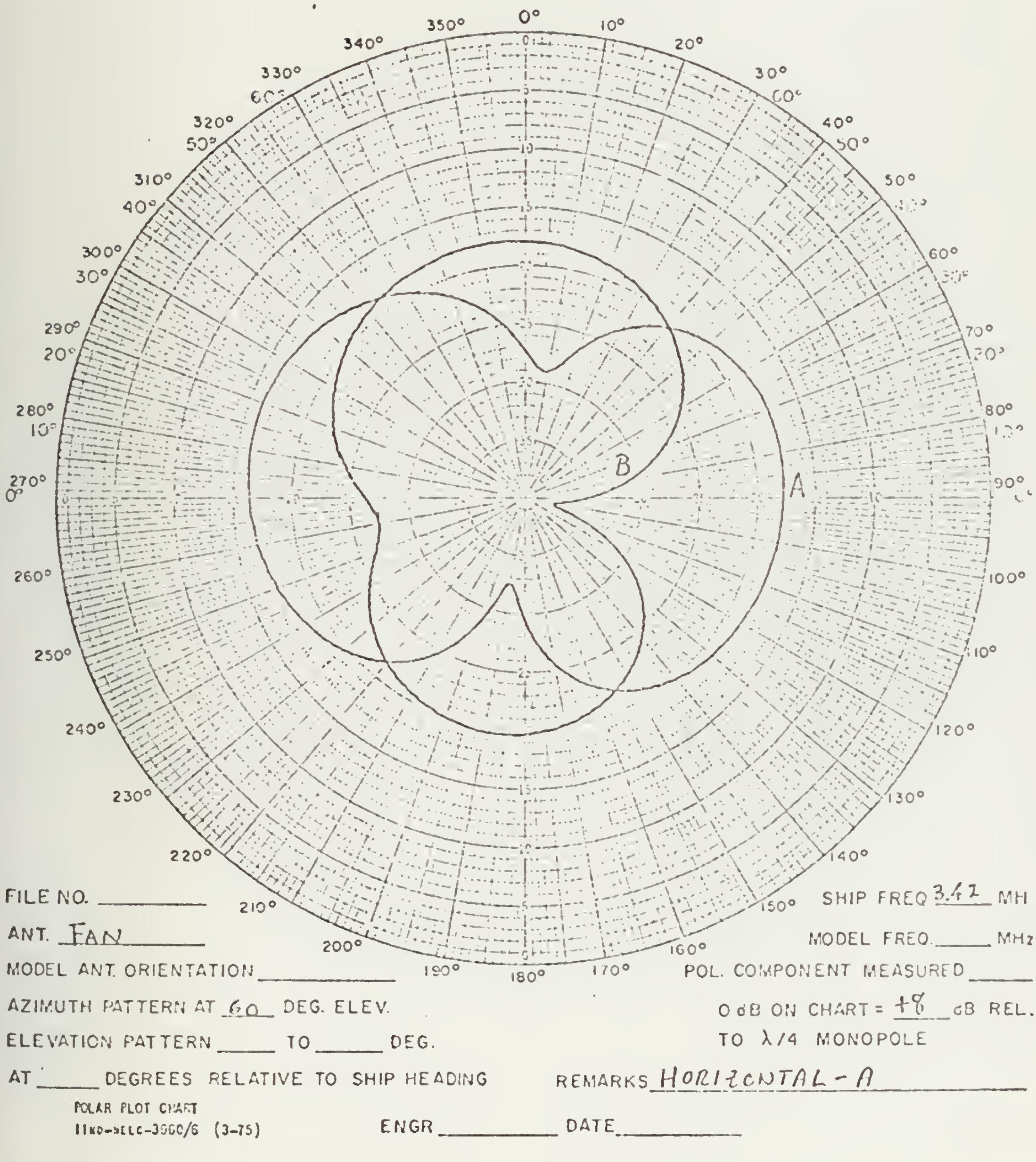


Figure 39

Fan radiation at 60 degrees elevation, 3.42 MHZ

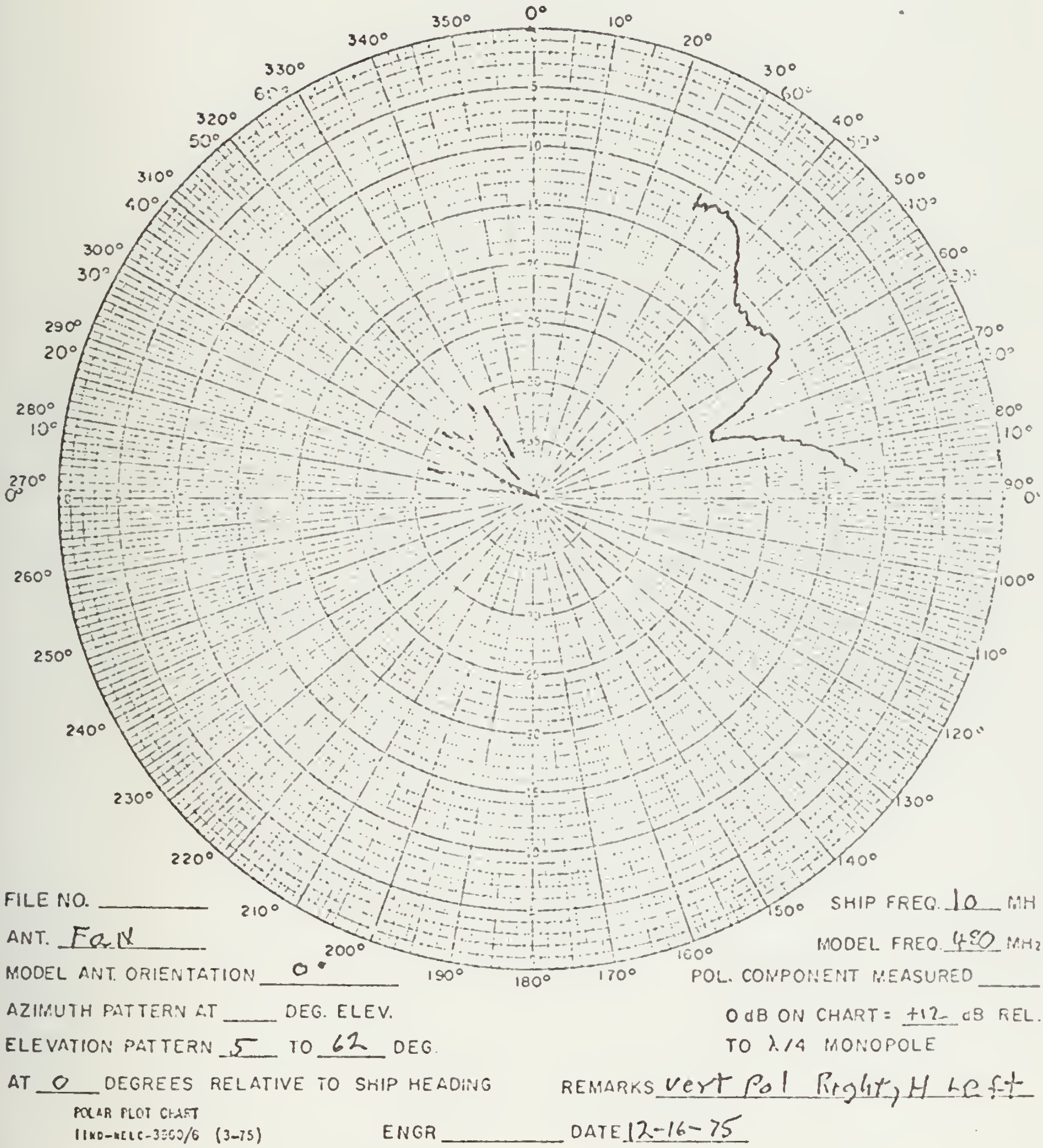


Figure 40

Fan radiation at zero degrees relative to ship's heading, 10 MHZ

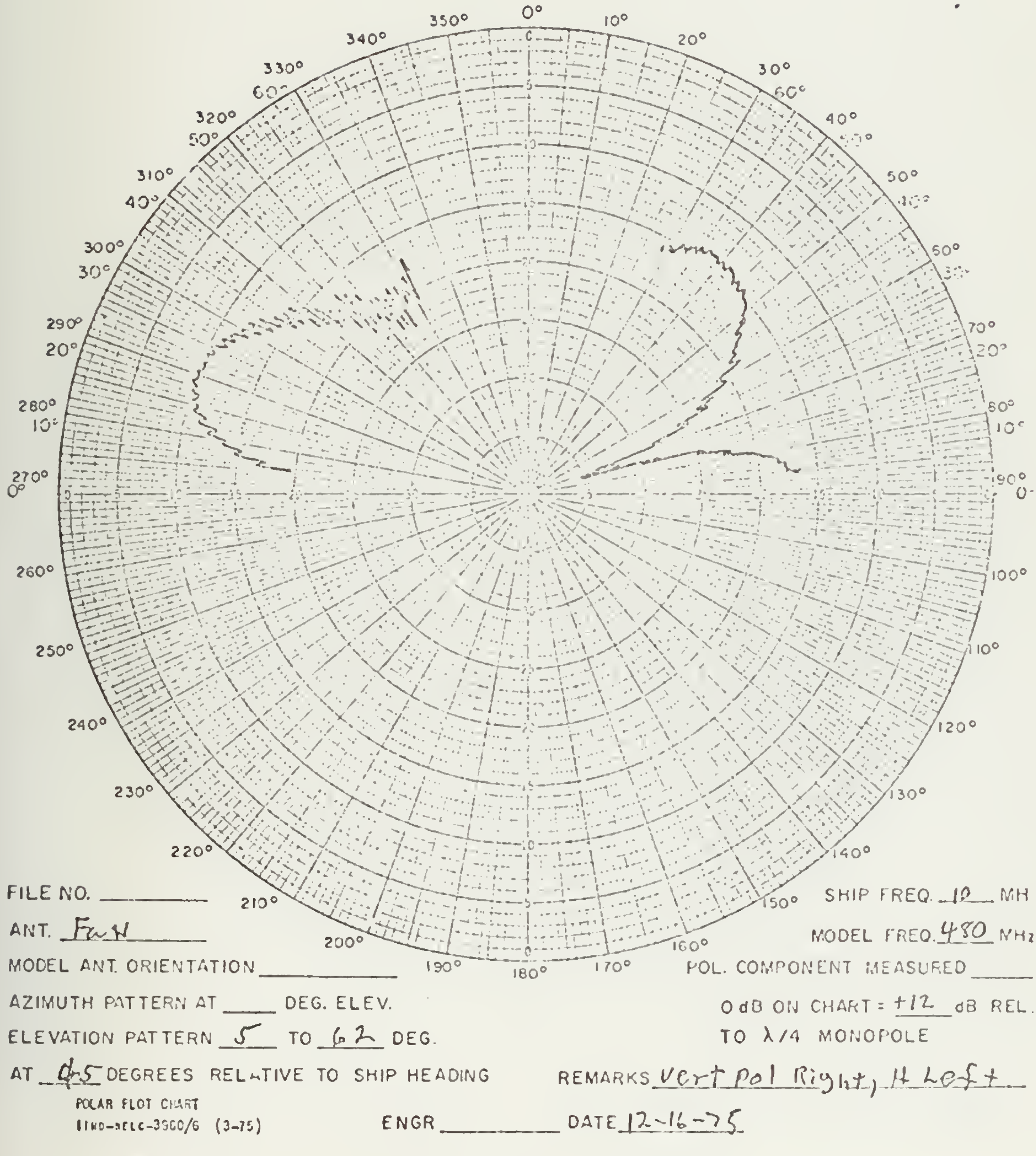


Figure 41

Fan radiation at 45 degrees relative to ship's heading, 10 MHZ

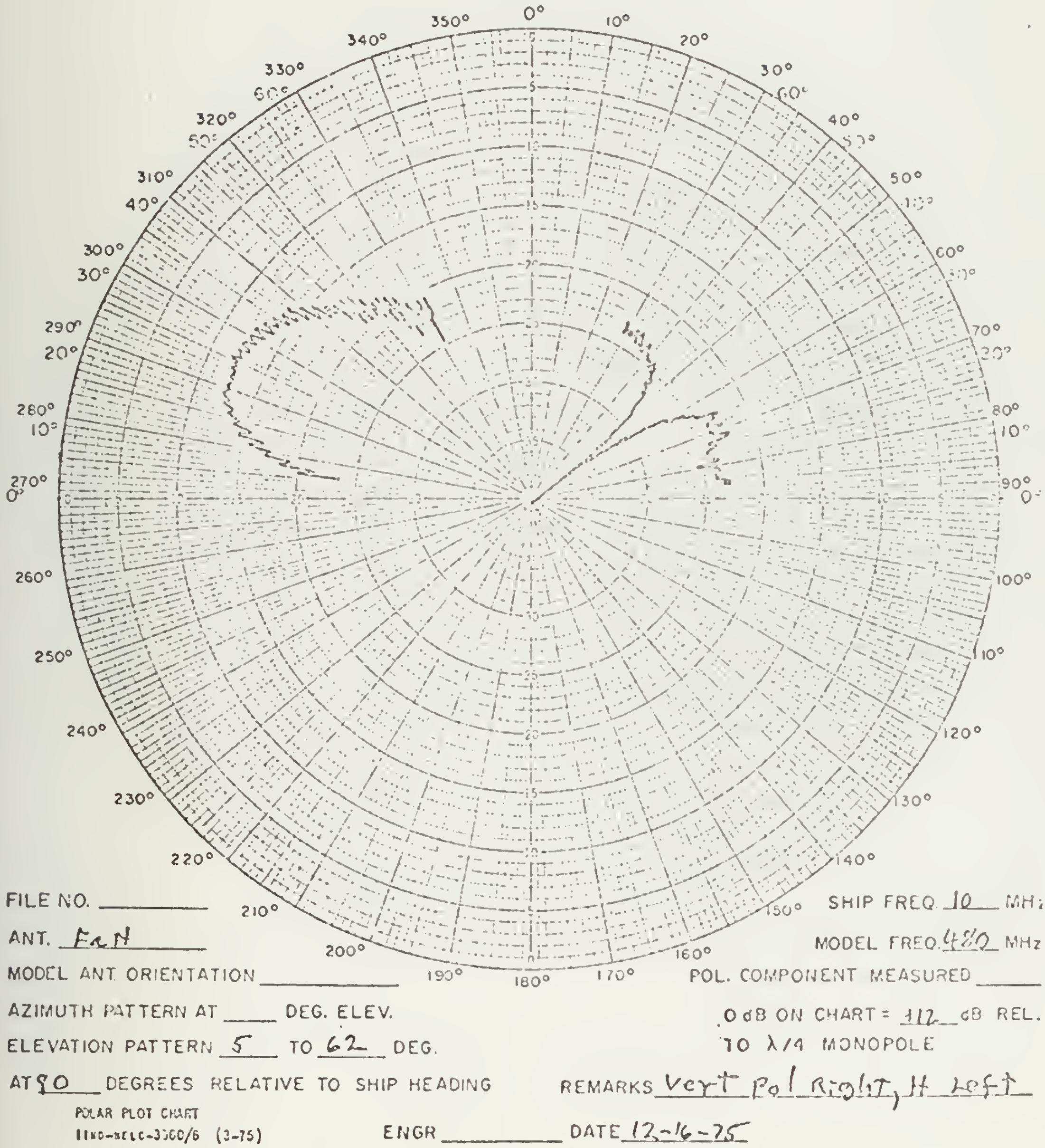


Figure 42

Fan radiation at 90 degrees relative to ship's heading, 10 MHZ

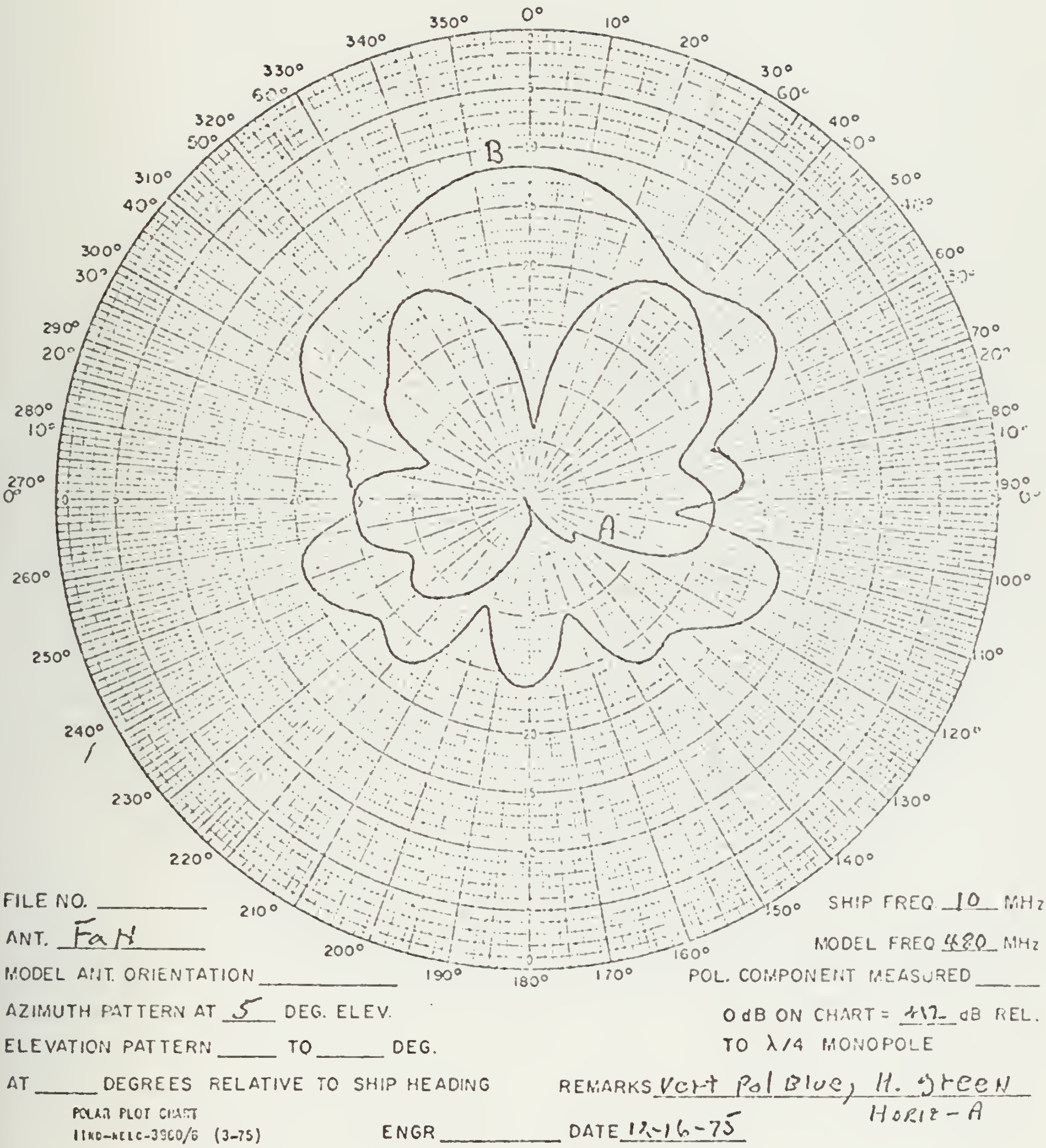


Figure 43

Fan radiation at five degrees elevation, 10 MHZ

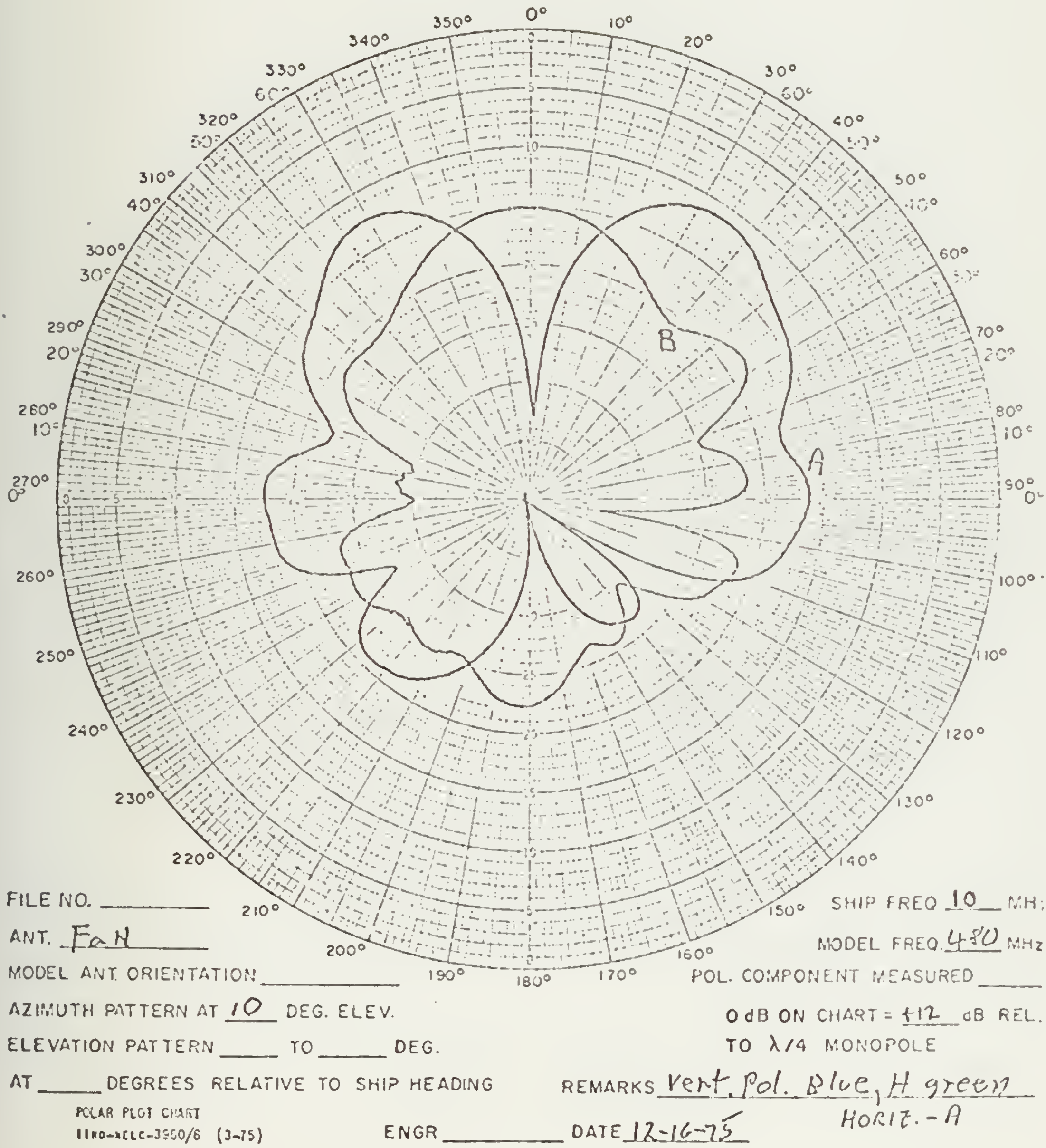


Figure 44

Fan radiation at 10 degrees elevation, 10 MHZ

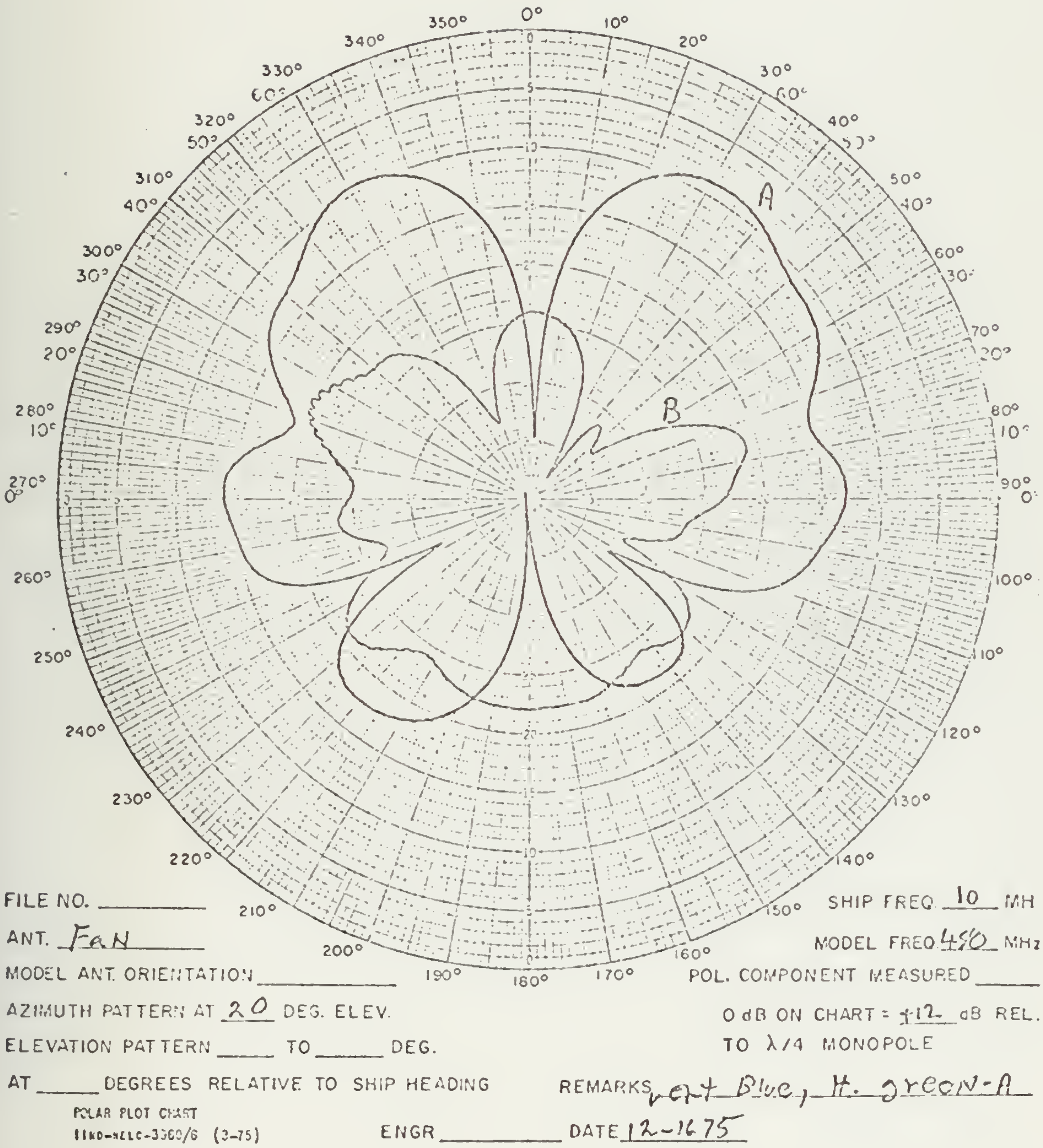


Figure 45

Fan radiation at 20 degrees elevation, 10 MHZ

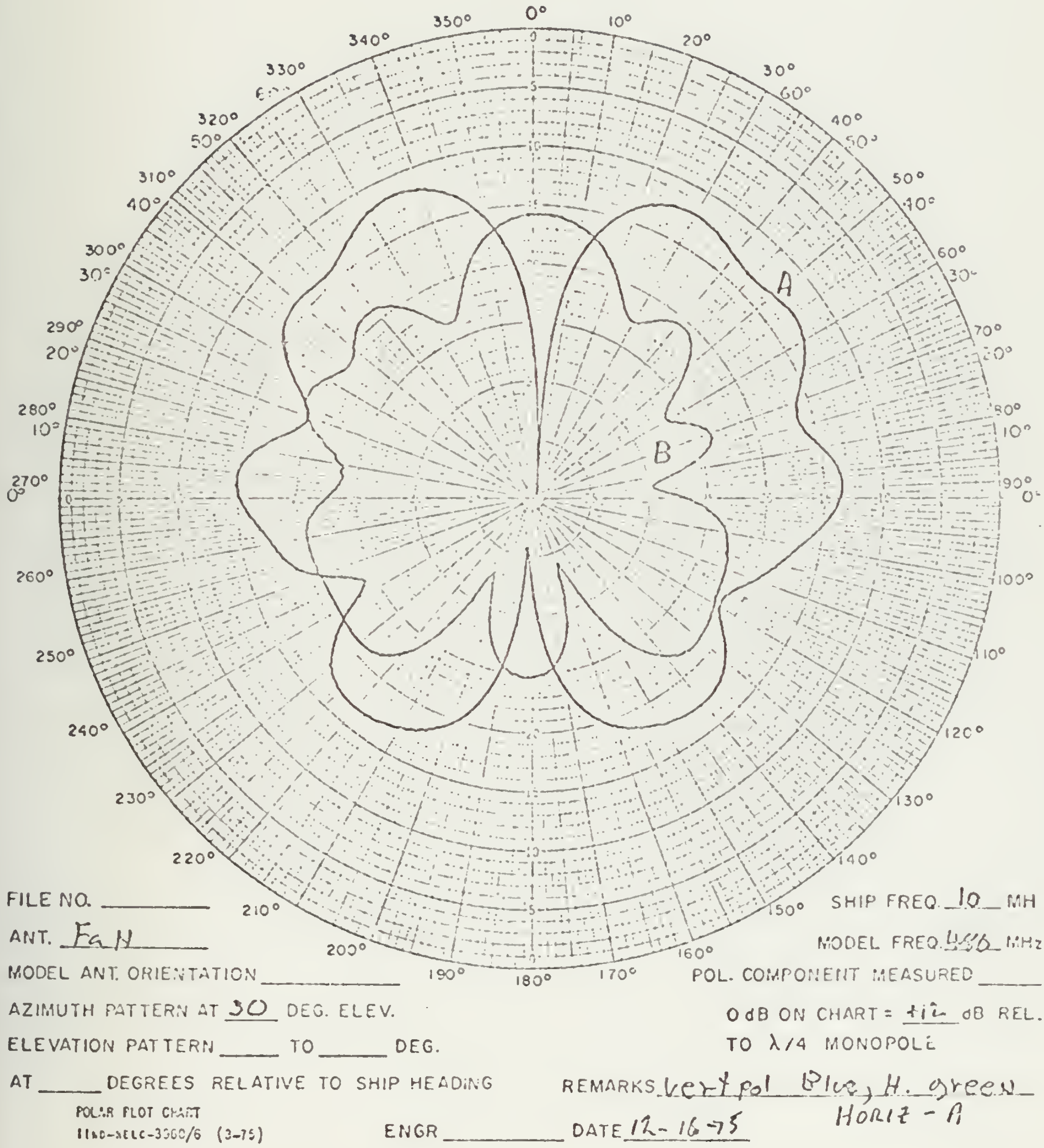


Figure 46

Fan radiation at 30 degrees elevation, 10 MHZ

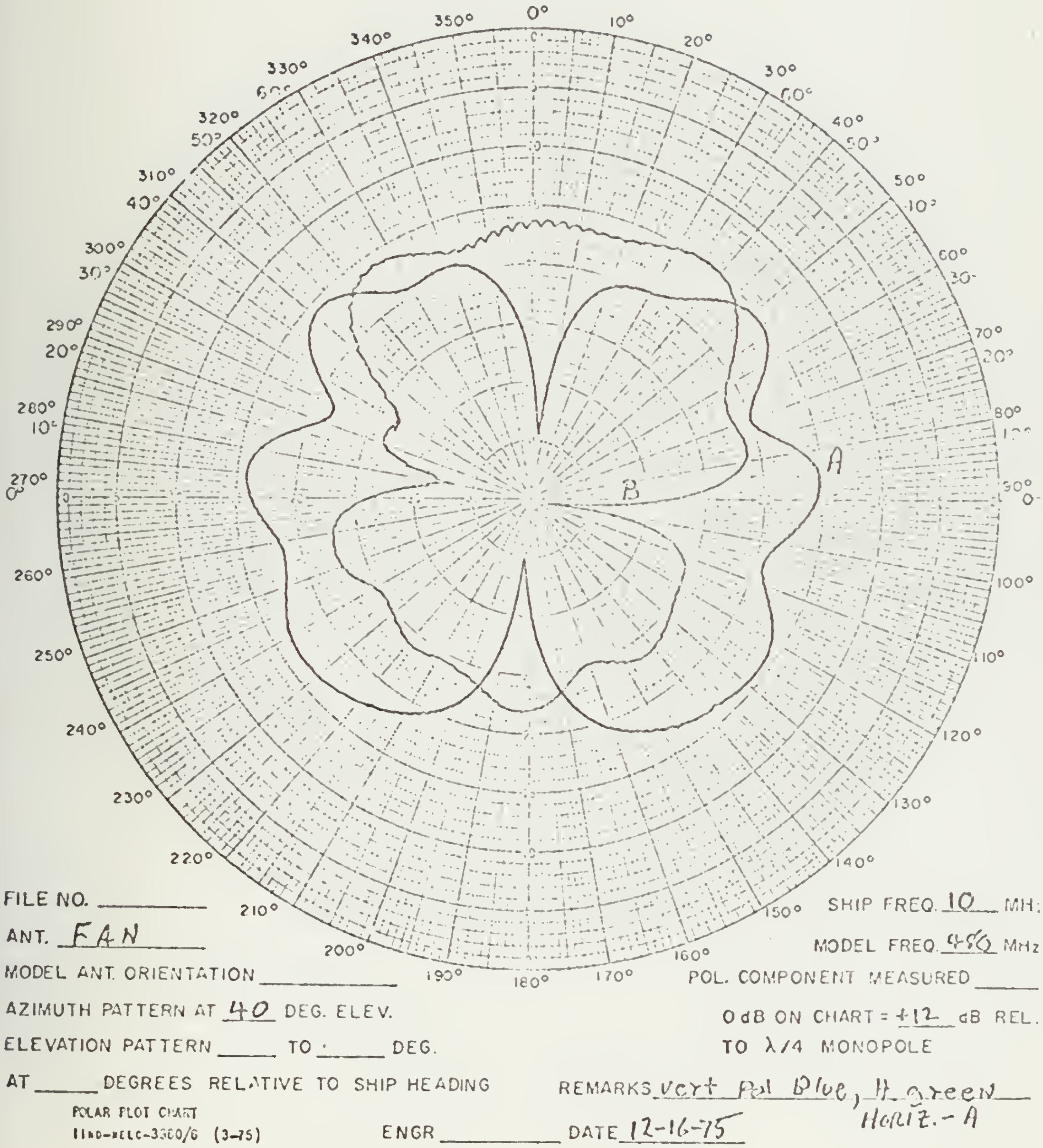


Figure 47

Fan radiation at 40 degrees elevation, 10 MHZ

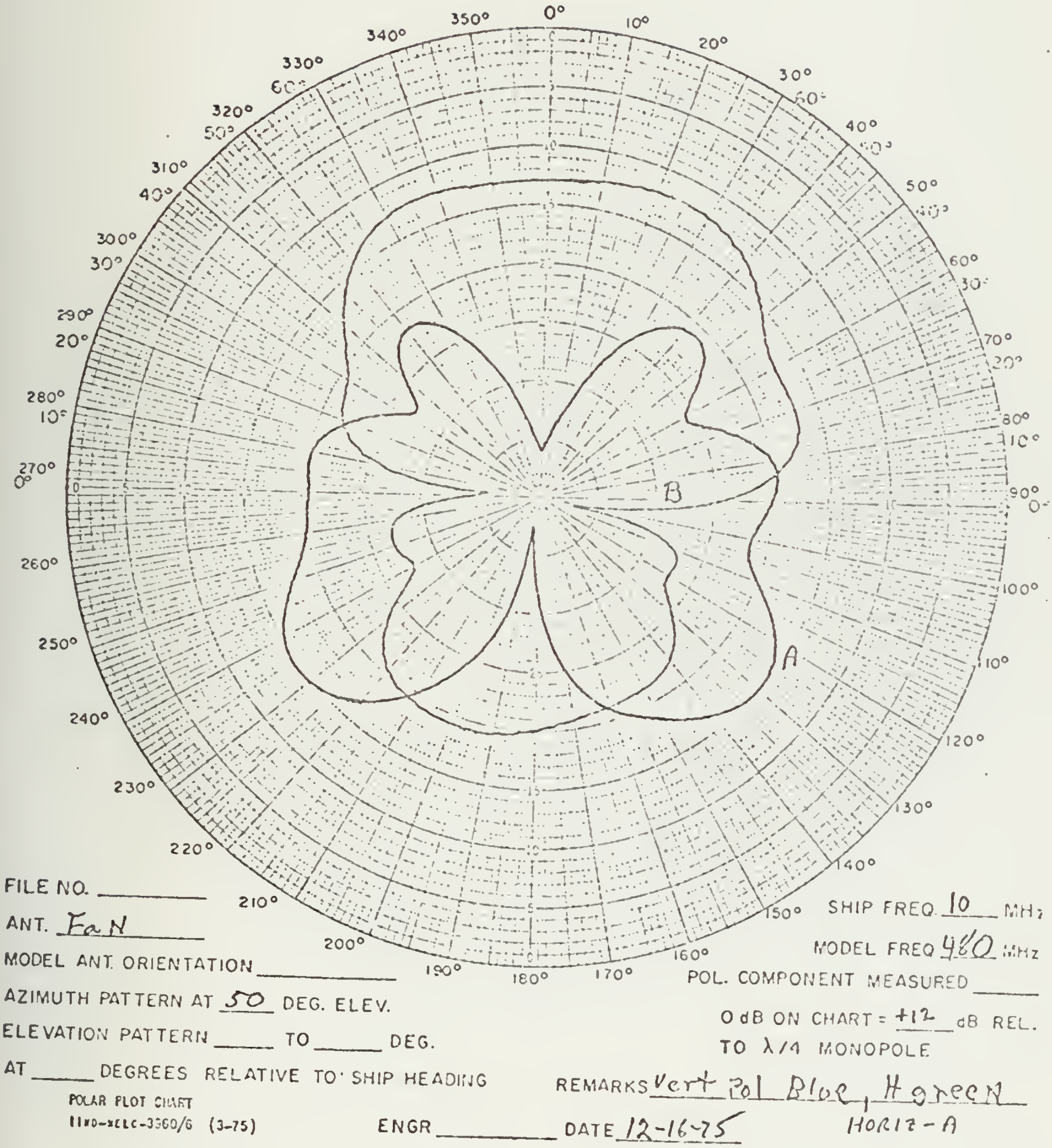


Figure 48

Fan radiation at 50 degrees elevation, 10 MHZ

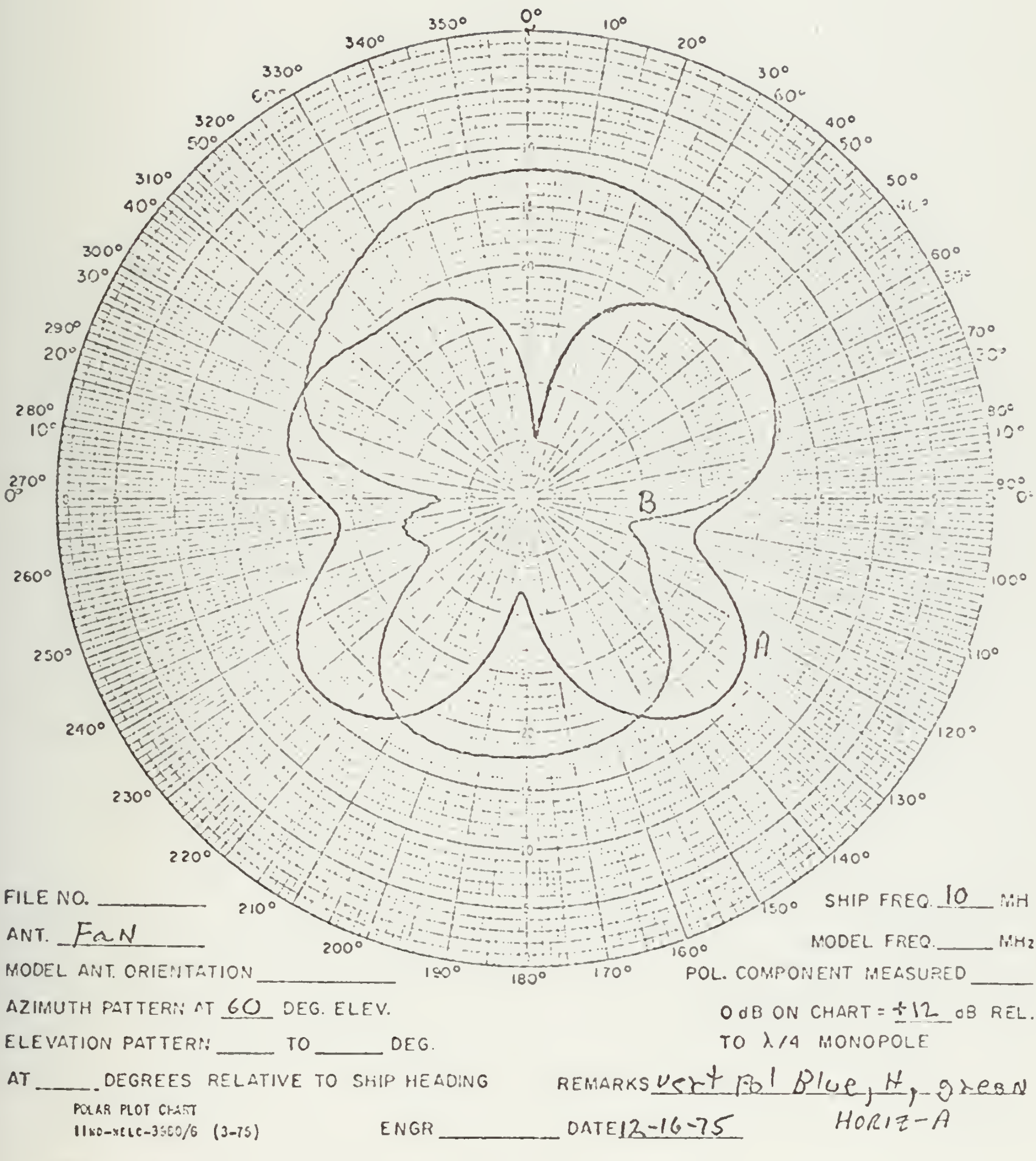


Figure 49

Fan radiation at 60 degrees elevation, 10 MHZ

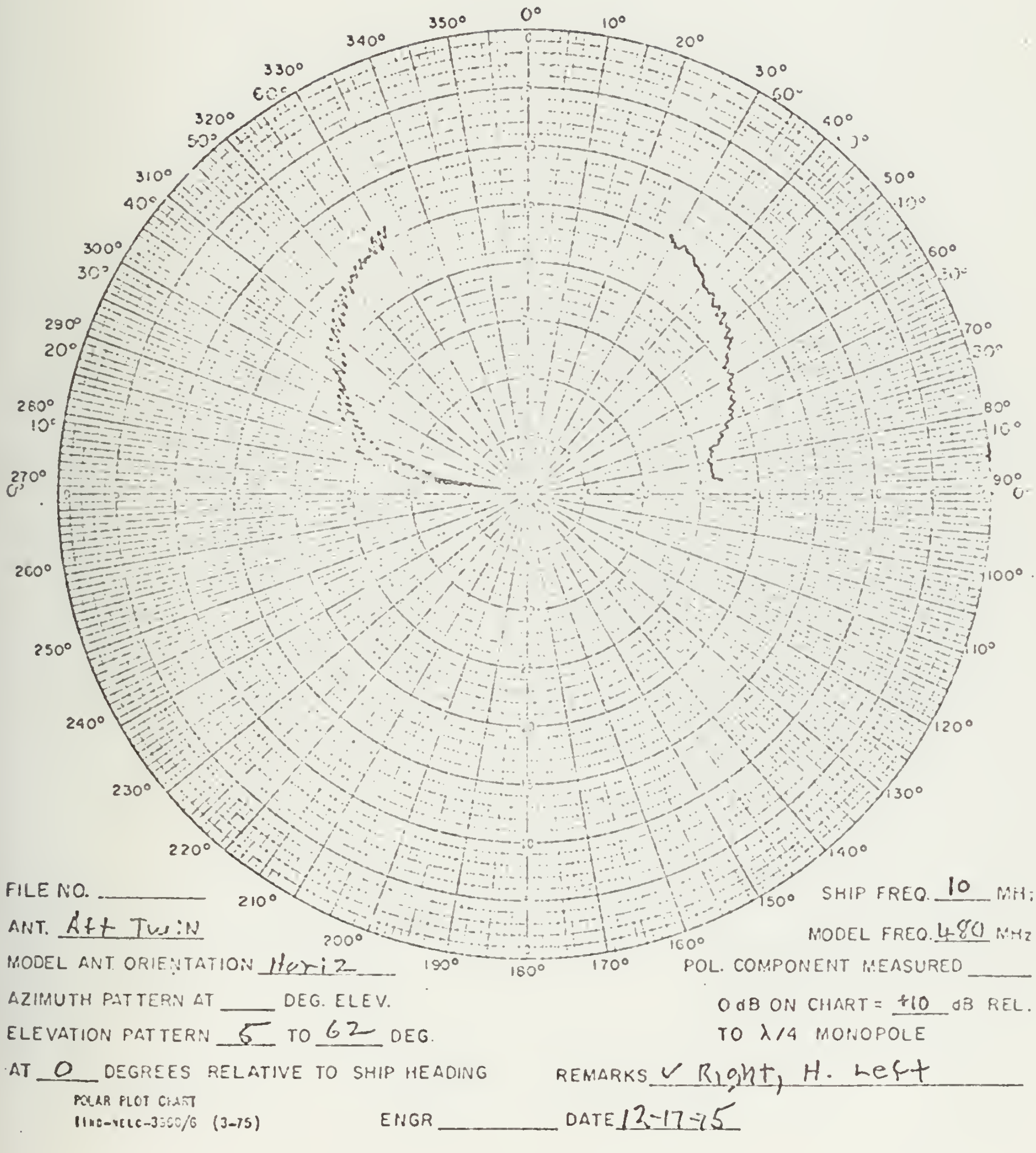


Figure 50

Twin whip radiation at zero degrees relative to ship's heading, 10 MHZ

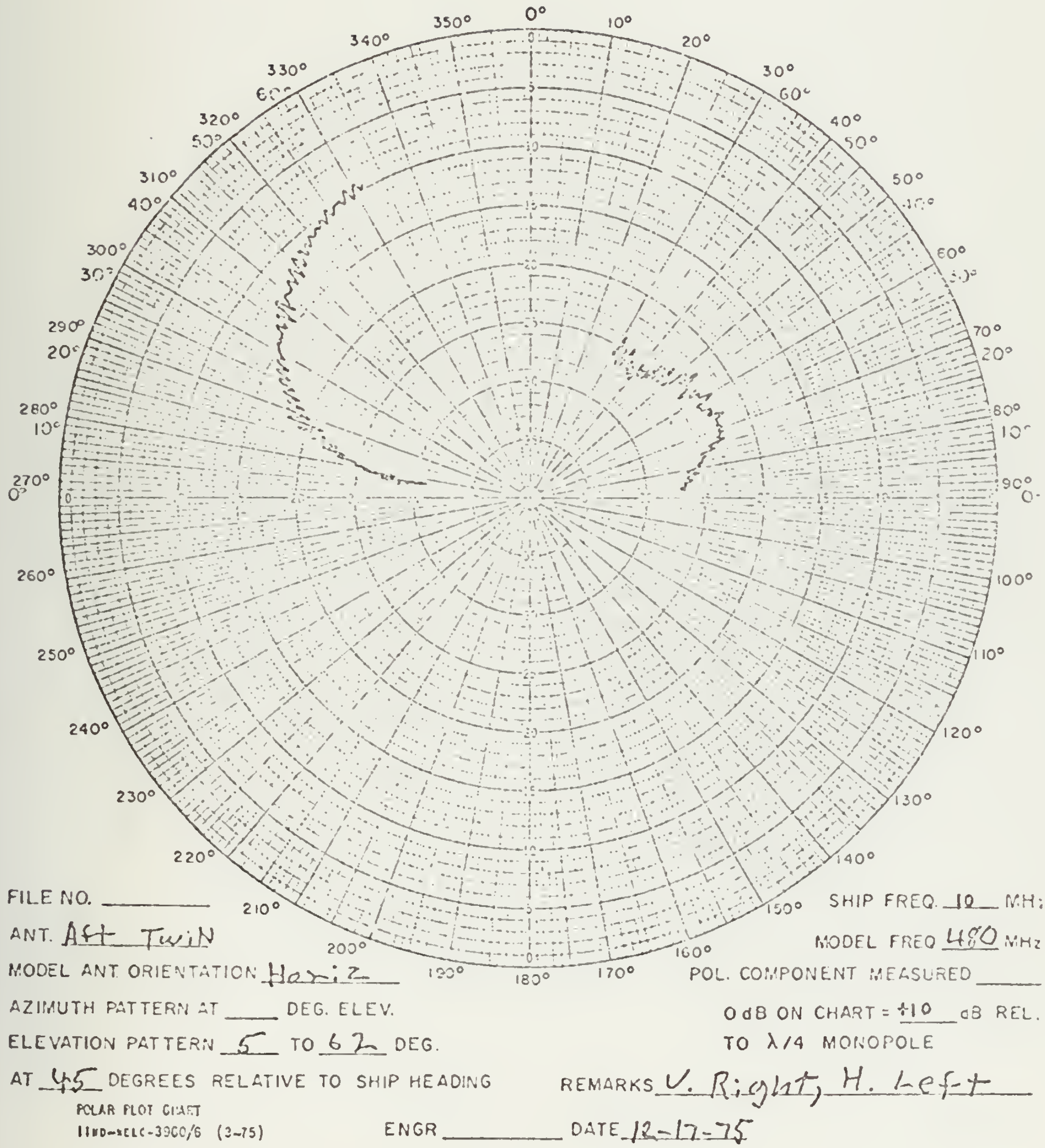


Figure 51

Twin whip radiation at 45 degrees relative to ship's heading, 10 MHZ

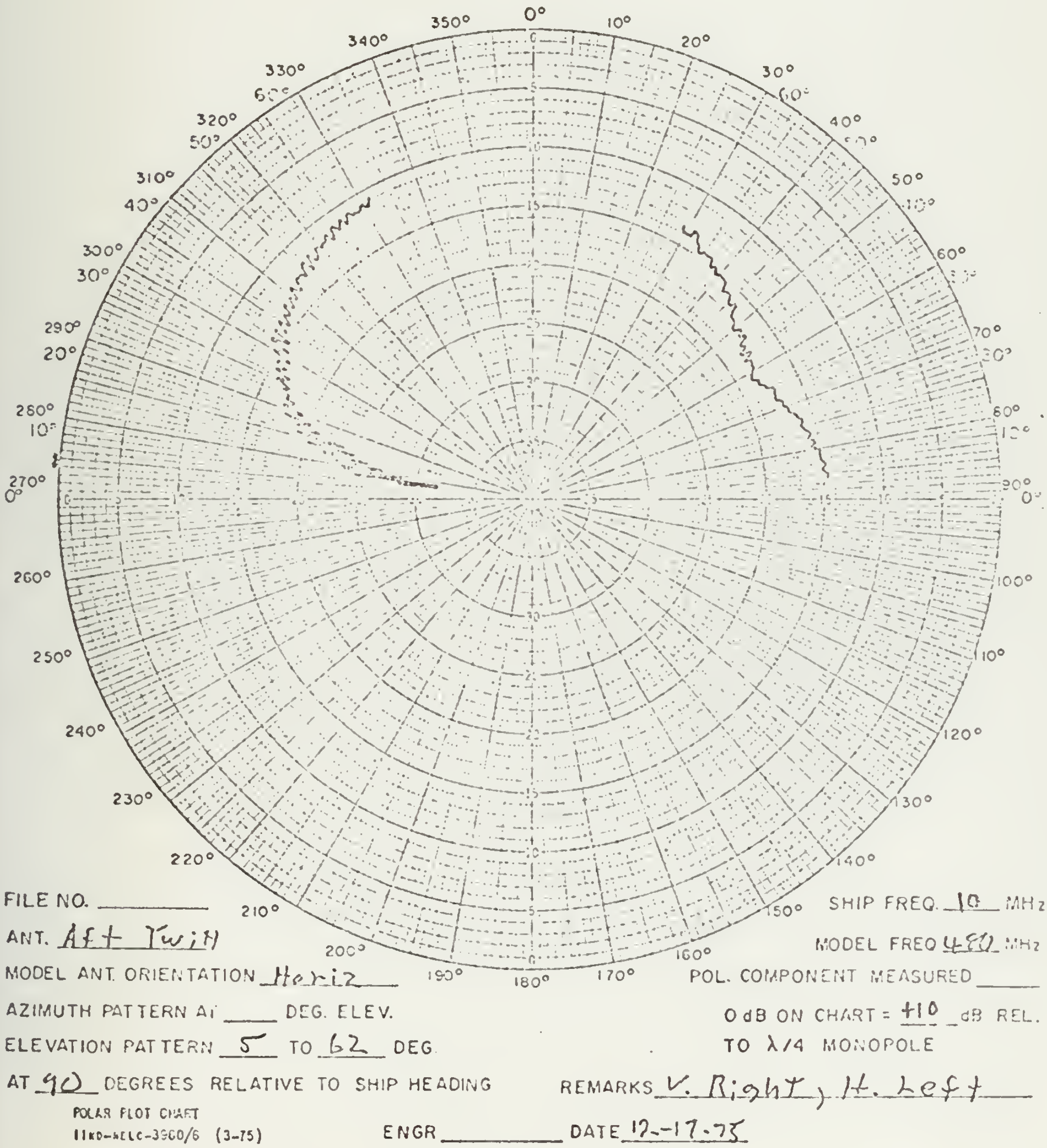


Figure 52

Twin whip radiation at 90 degrees relative to ship's heading, 10 MHZ

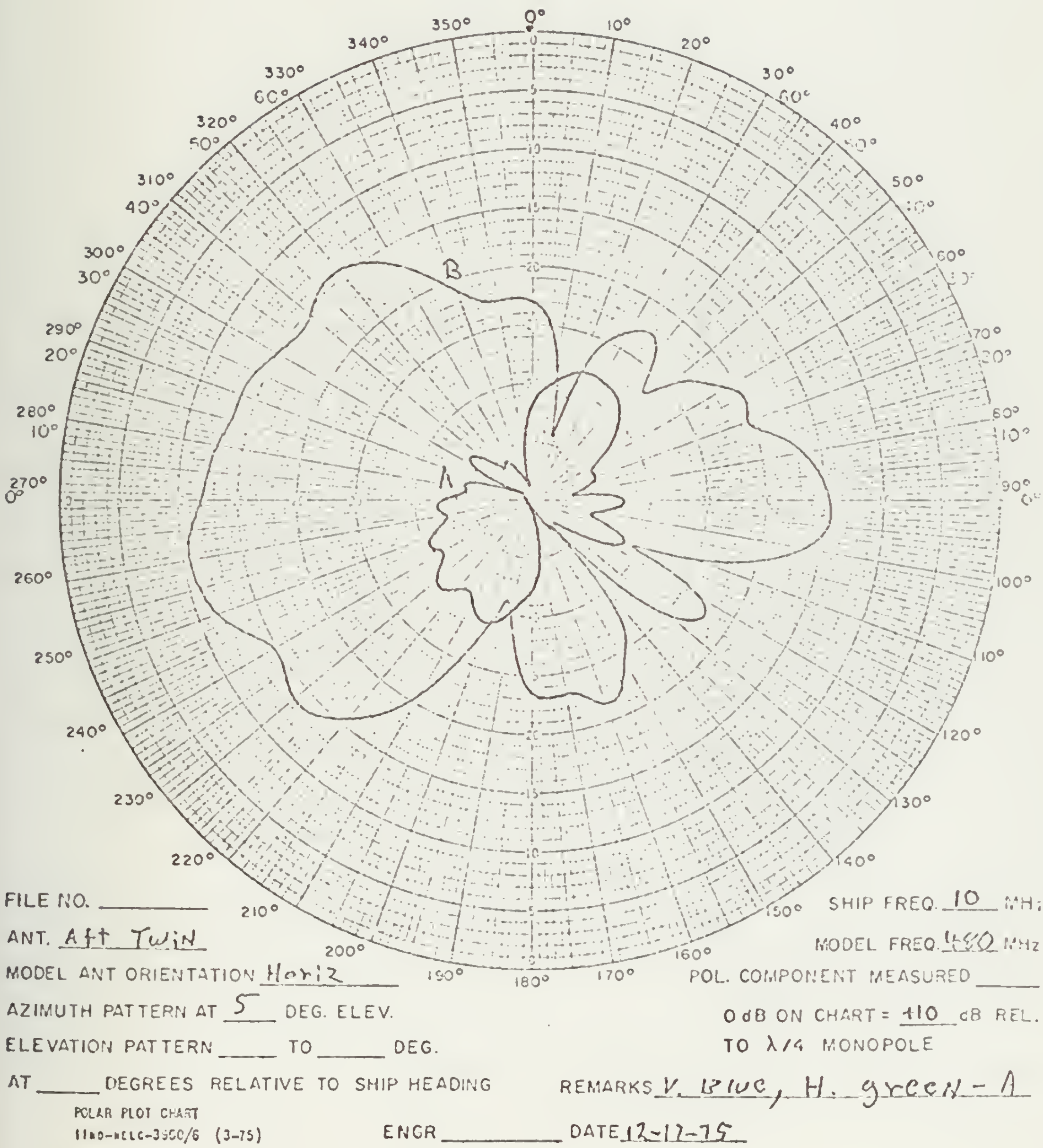


Figure 53

Twin whip radiation at five degrees elevation, 10 MHZ

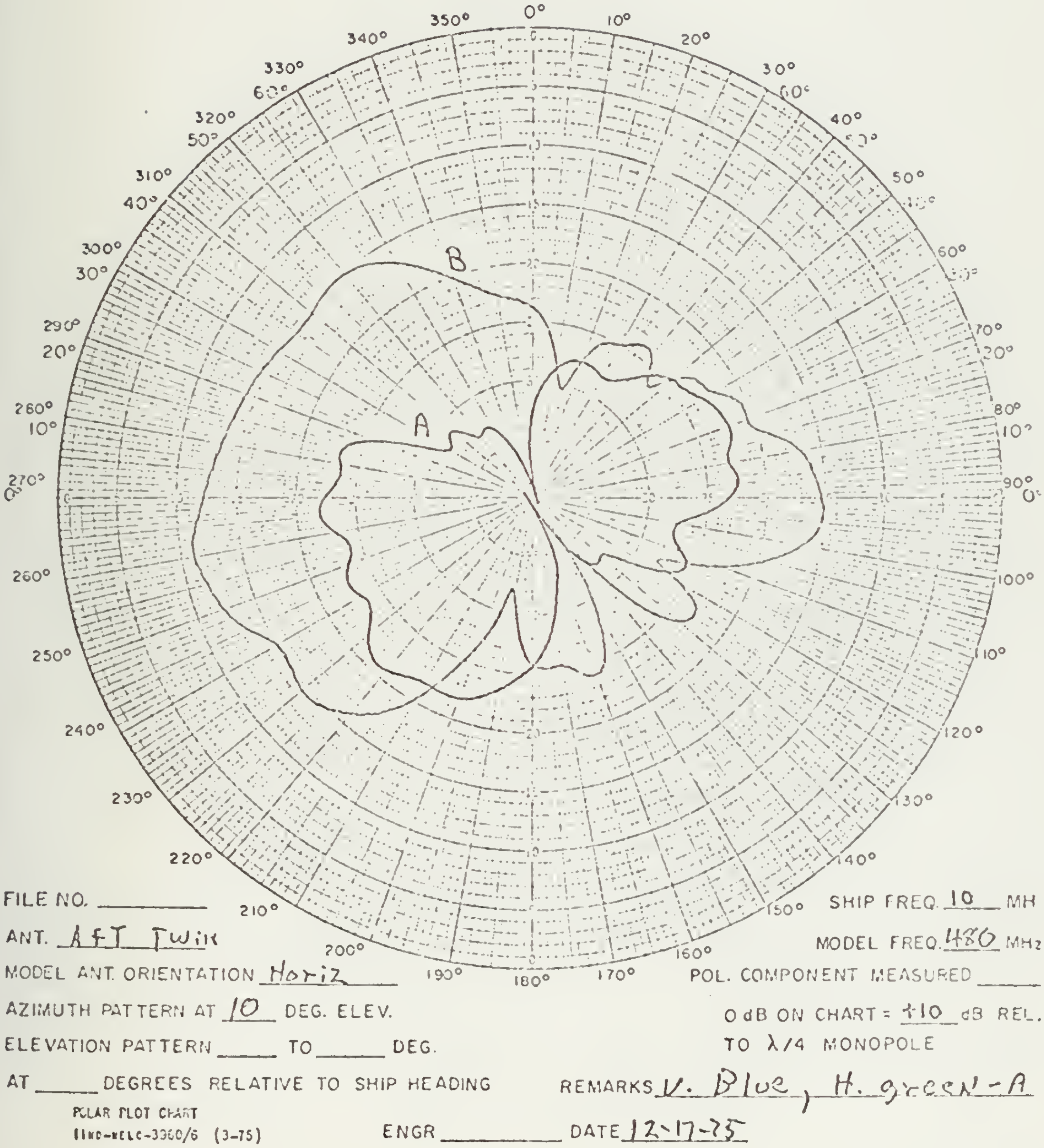


Figure 54

Twin whip radiation at 10 degrees elevation, 10 MHZ

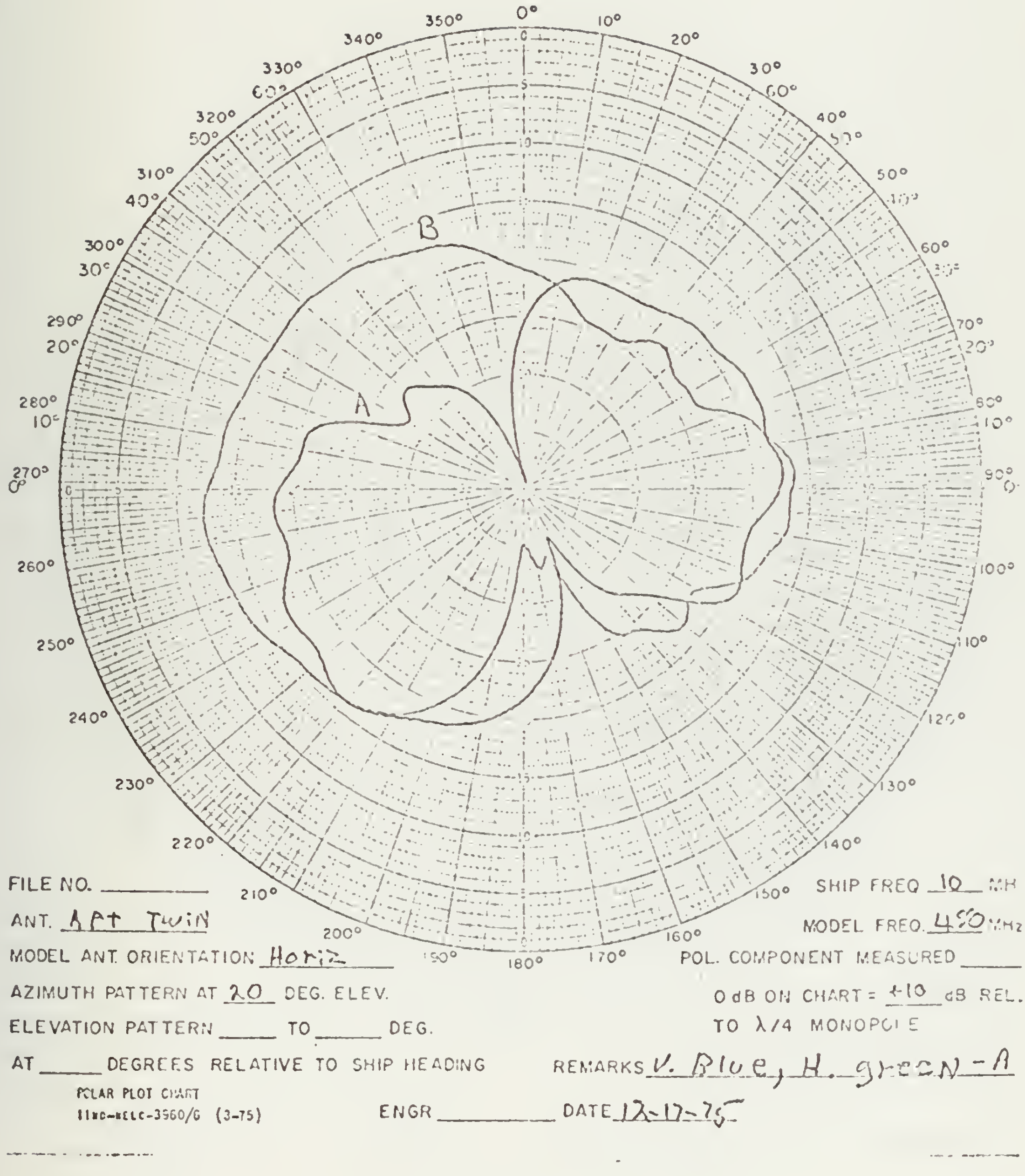


Figure 55

Twin whip radiation at 20 degrees elevation, 10 MHZ

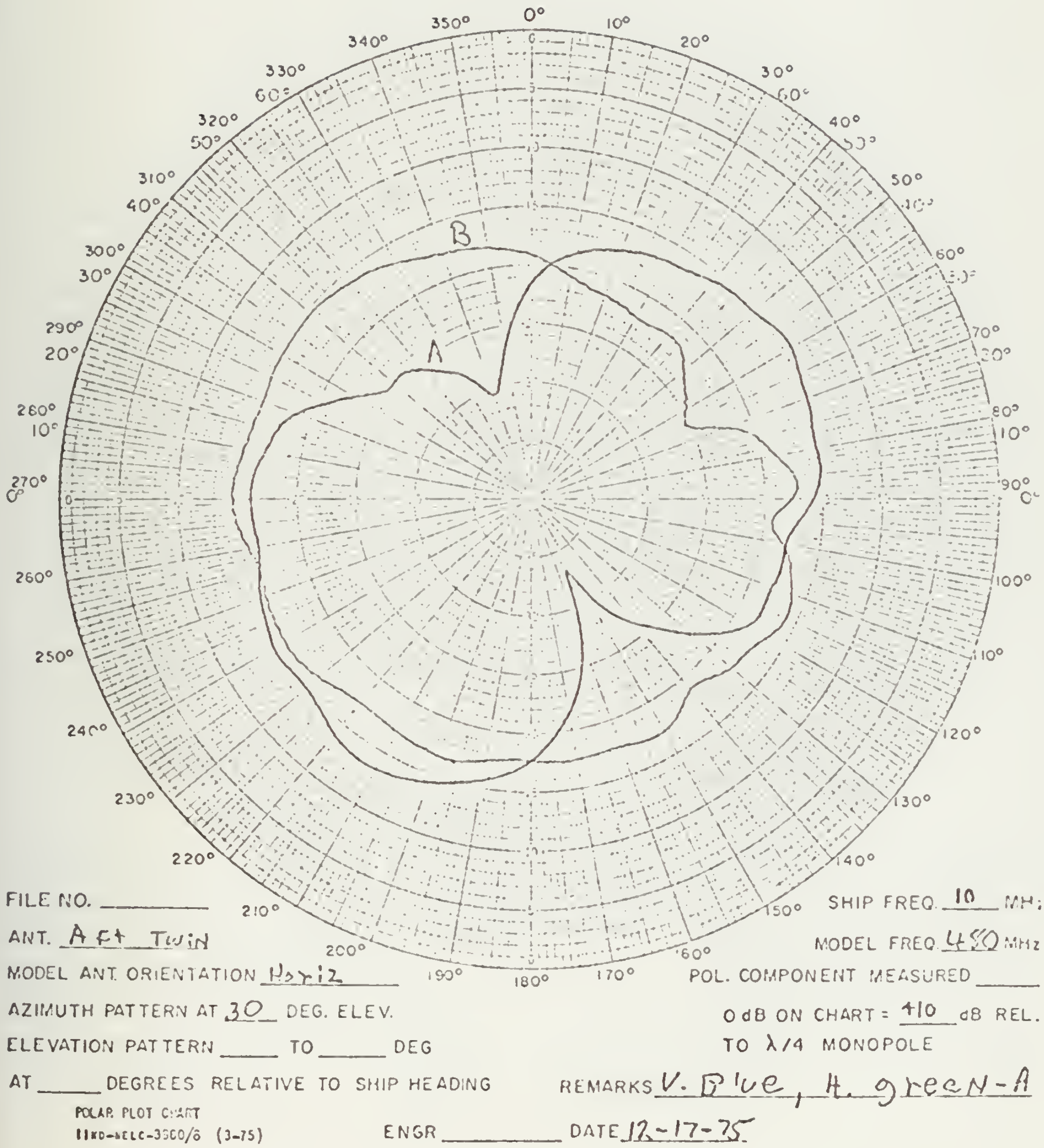
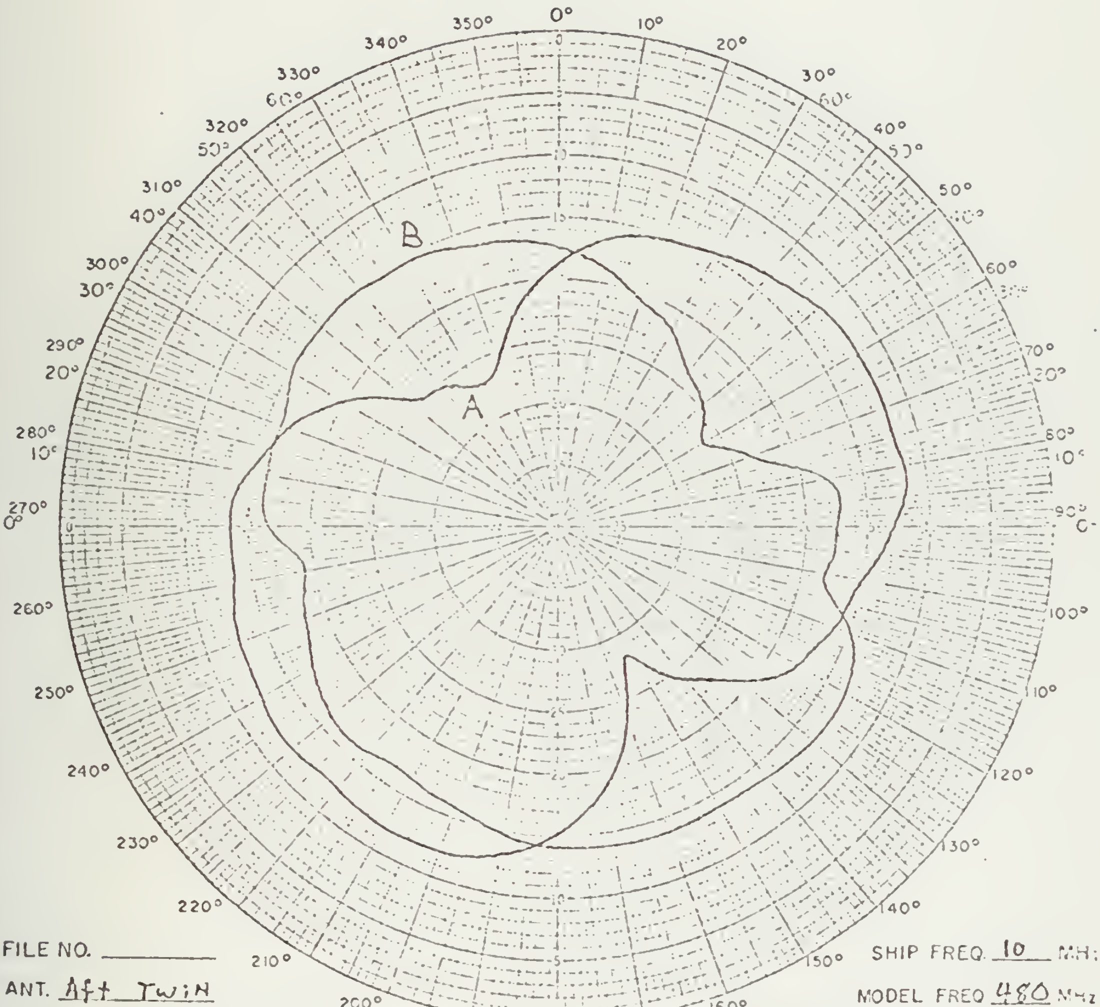


Figure 56

Twin whip radiation at 30 degrees elevation, 10 MHZ



FILE NO. ________

ANT. Aft Twin

MODEL ANT. ORIENTATION Horiz

AZIMUTH PATTERN AT 40 DEG. ELEV.

ELEVATION PATTERN ____ TO ____ DEG.

AT ____ DEGREES RELATIVE TO SHIP HEADING

POLAR PLOT CHART

SHIP FREQ. 10 MHz

MODEL FREQ 480 MHz

POL. COMPONENT MEASURED ______

0 dB ON CHART = +10 dB REL. TO λ/4 MONOPOLE

REMARKS V. Blue, H. green-A

ENGR ________ DATE 12-17-75

Figure 57

Twin whip radiation at 40 degrees elevation, 10 MHZ

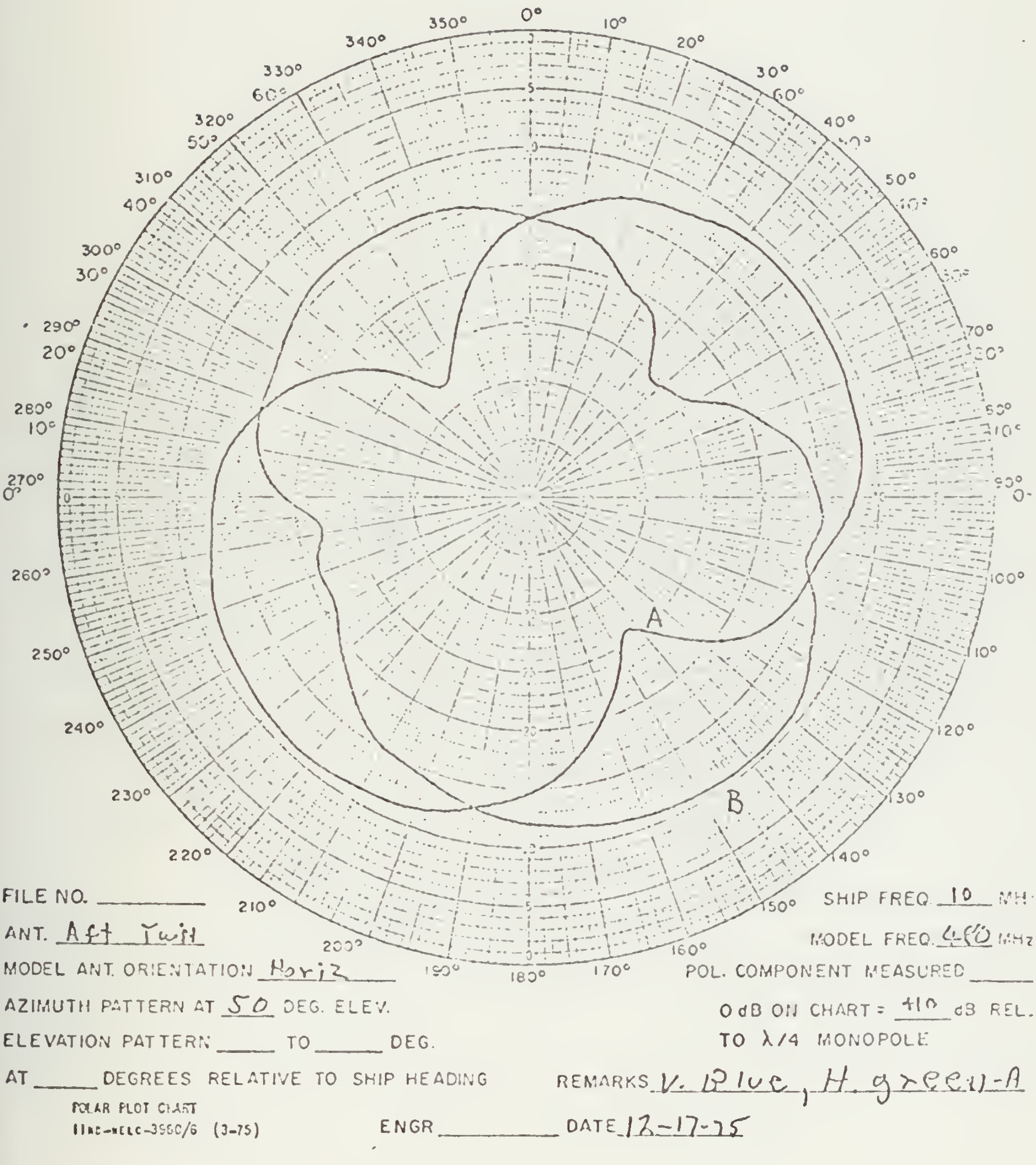


Figure 58

Twin whip radiation at 50 degrees elevation, 10 MHZ

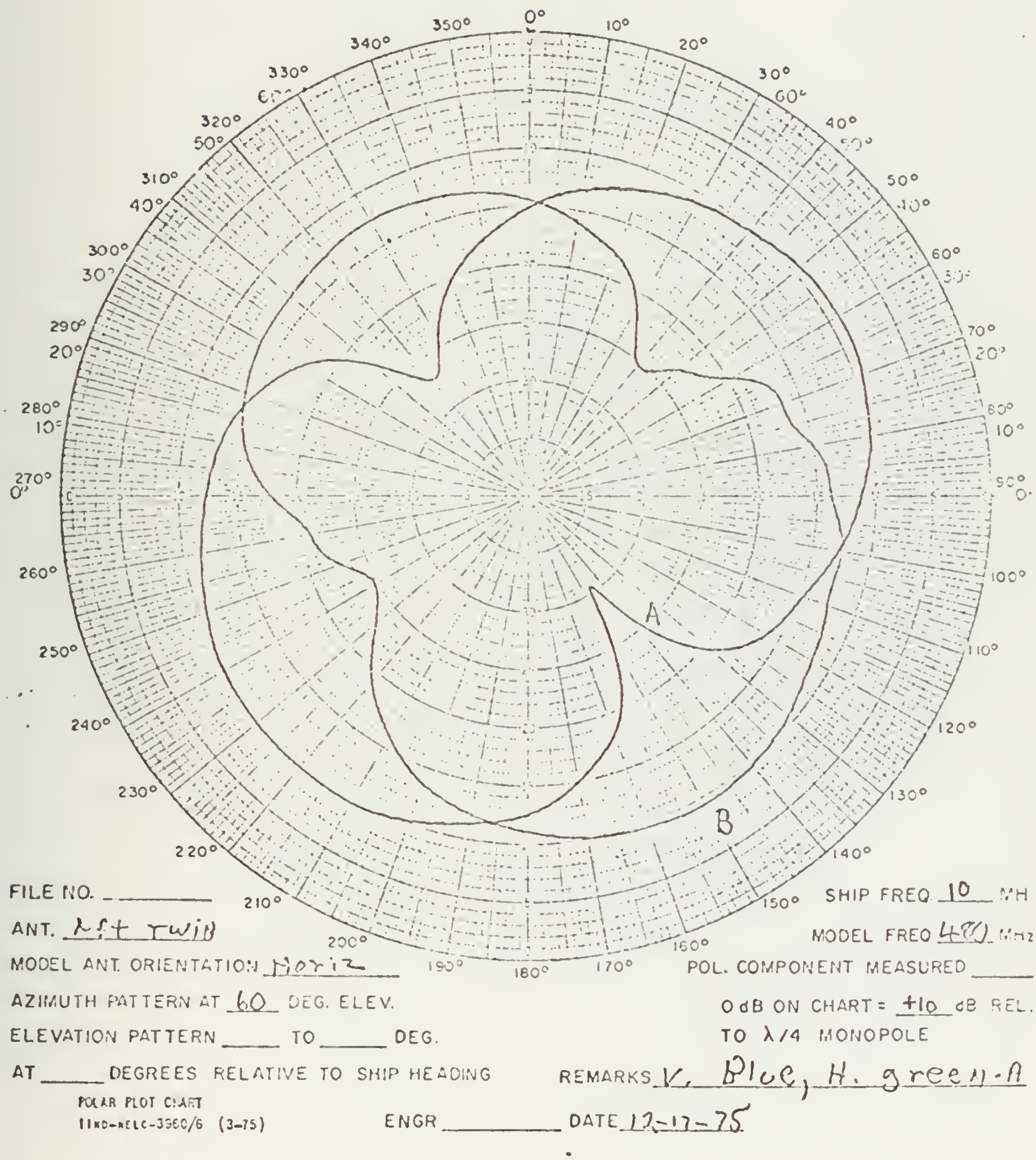


Figure 59

Twin whip radiation at 60 degrees elevation, 10 MHZ

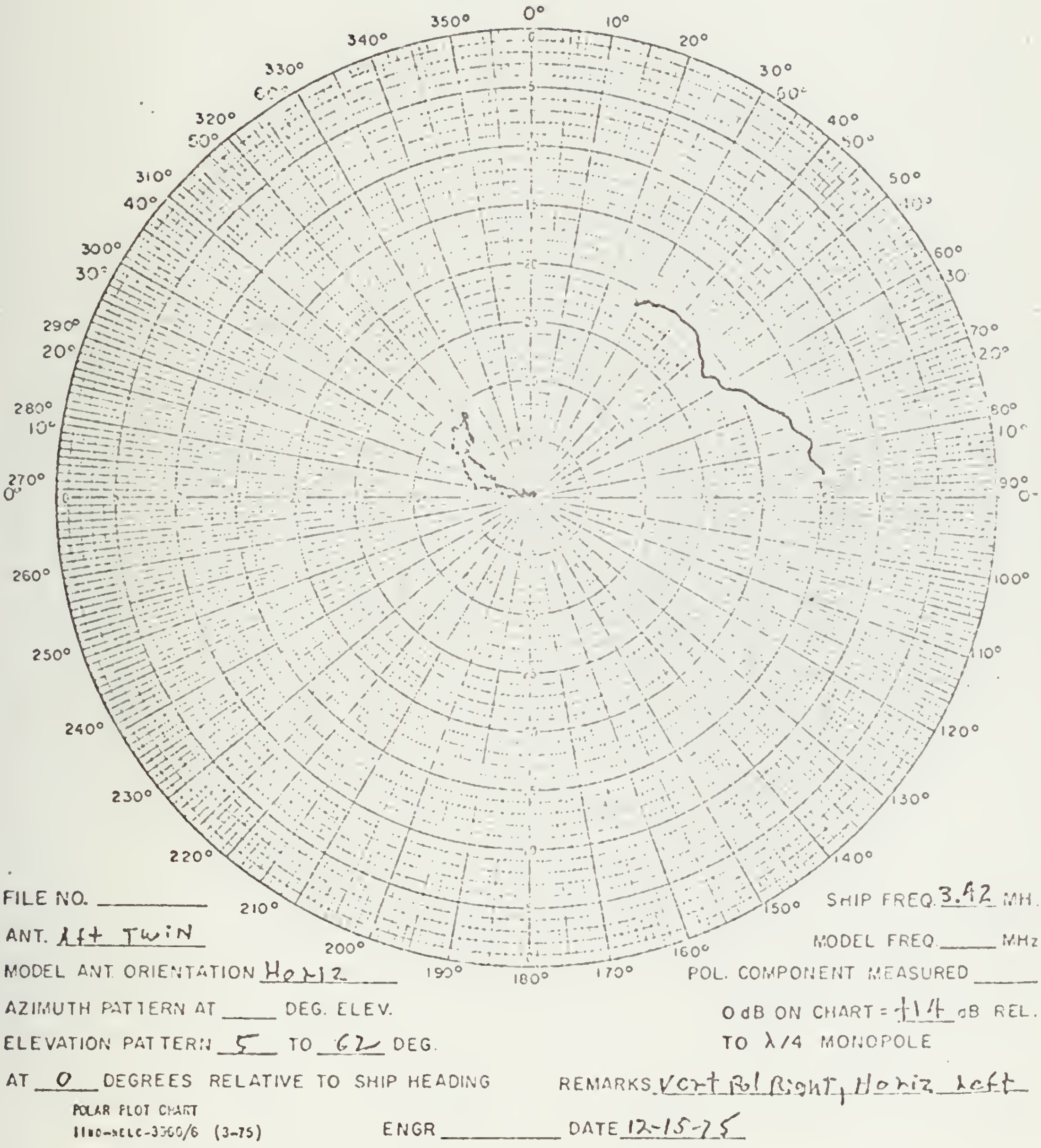


Figure 60

Twin whip radiation at zero degrees relative to ship's heading, 3.42 MHZ

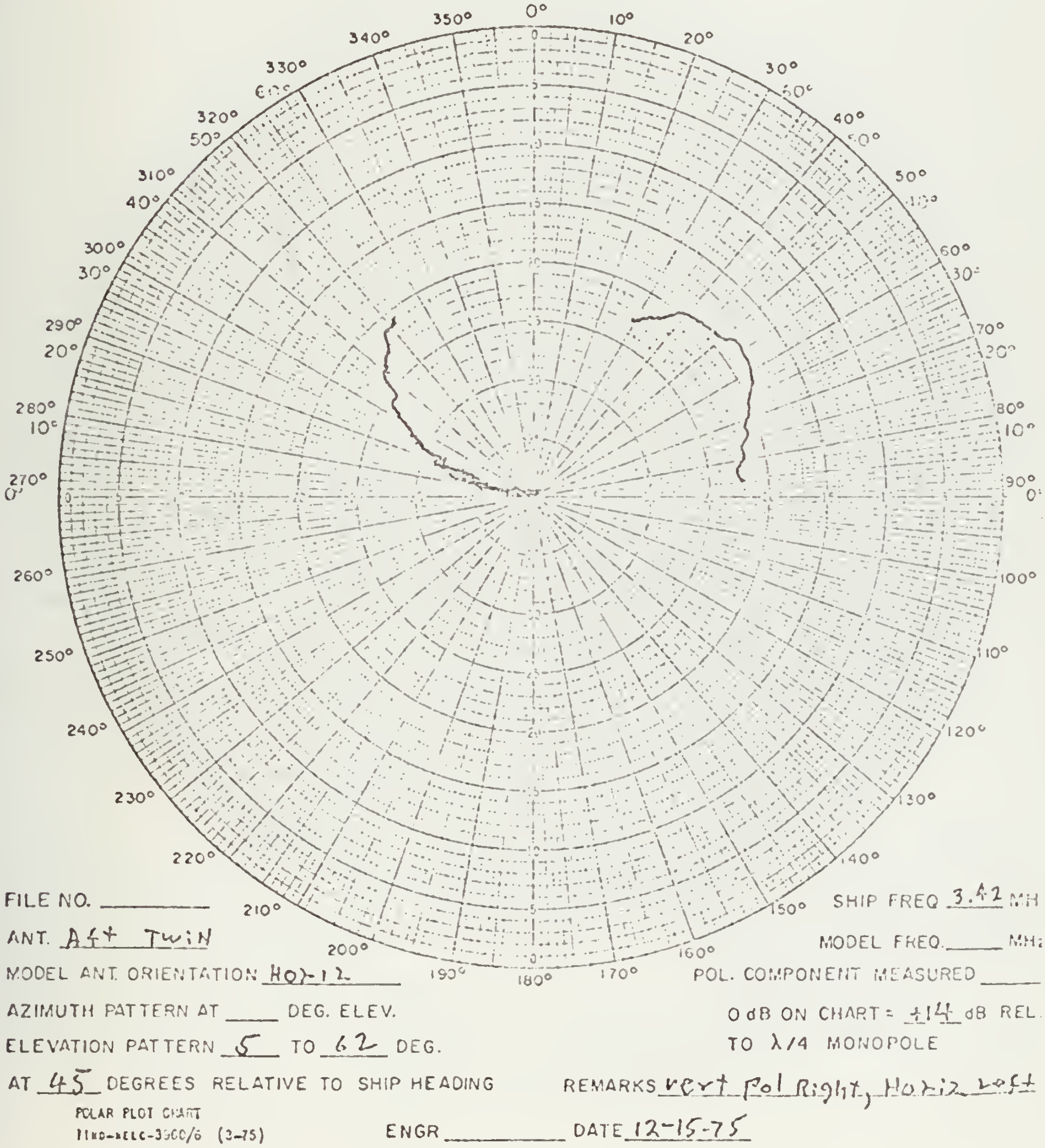


Figure 61

Twin whip radiation at 45 degrees relative to ship's heading, 3.42 MHZ

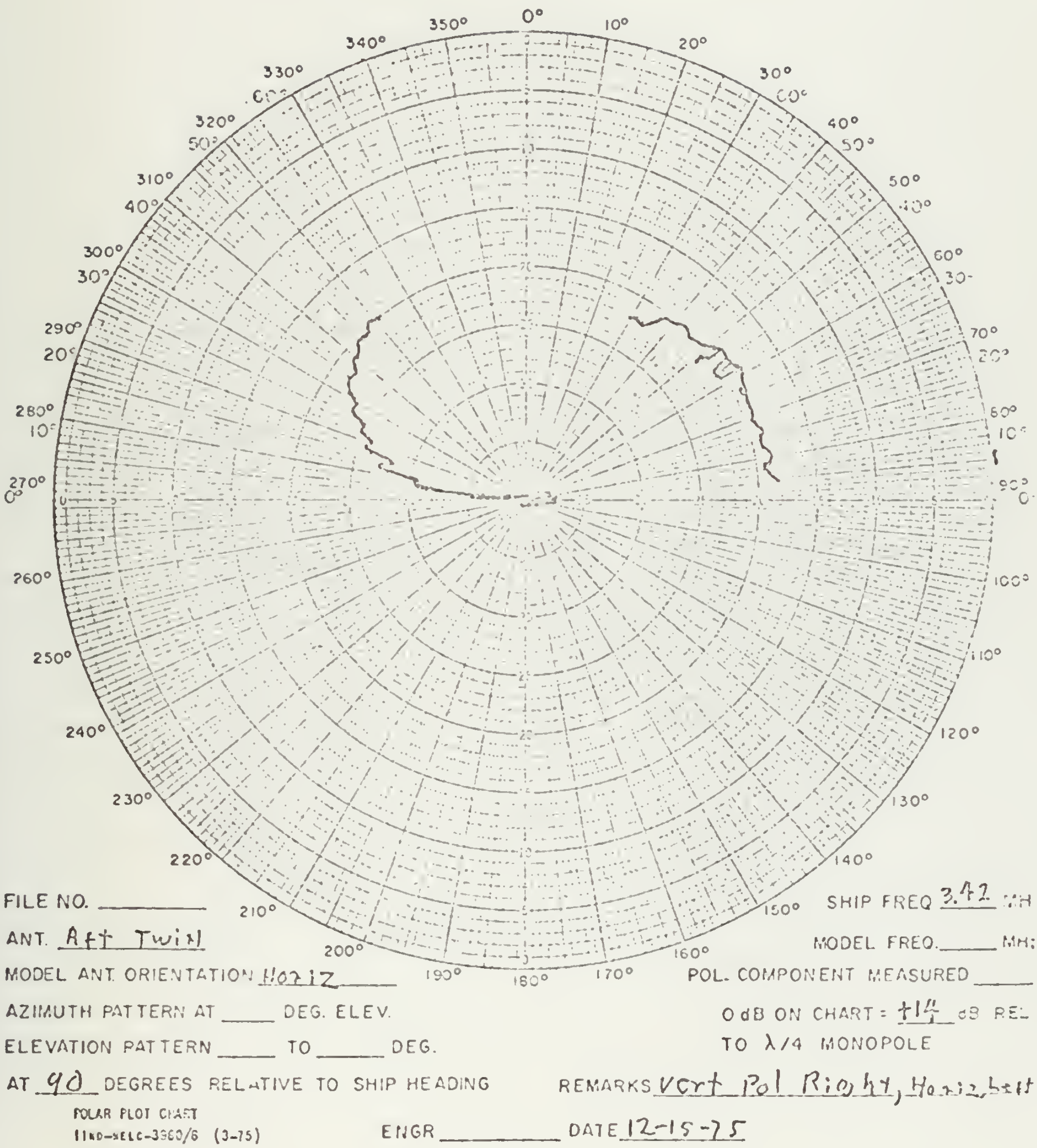


Figure 62

Twin whip radiation at 90 degrees relative to ship's heading, 3.42 MHZ

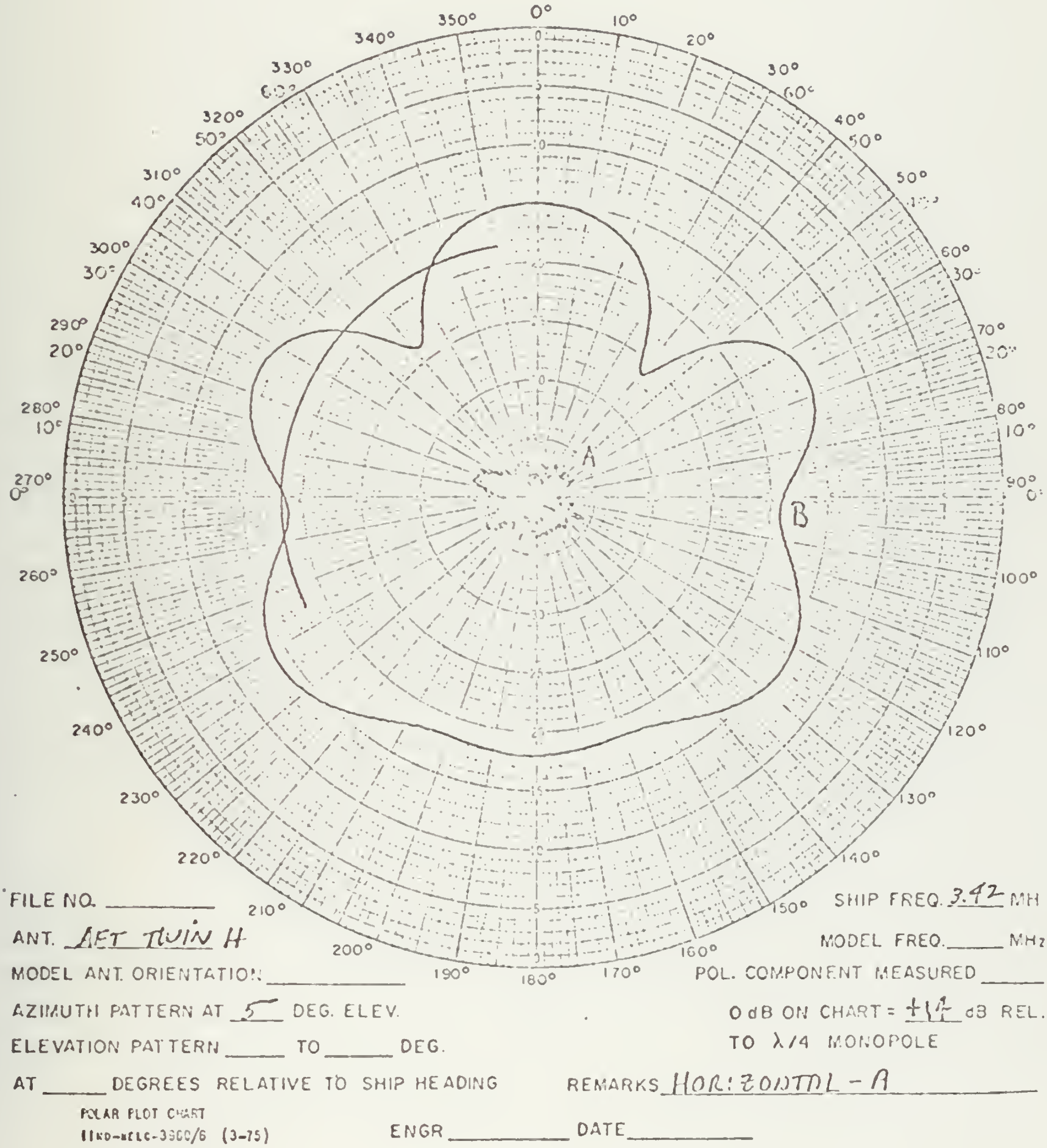


Figure 63

Twin whip radiation at five degrees elevation, 3.42 MHZ

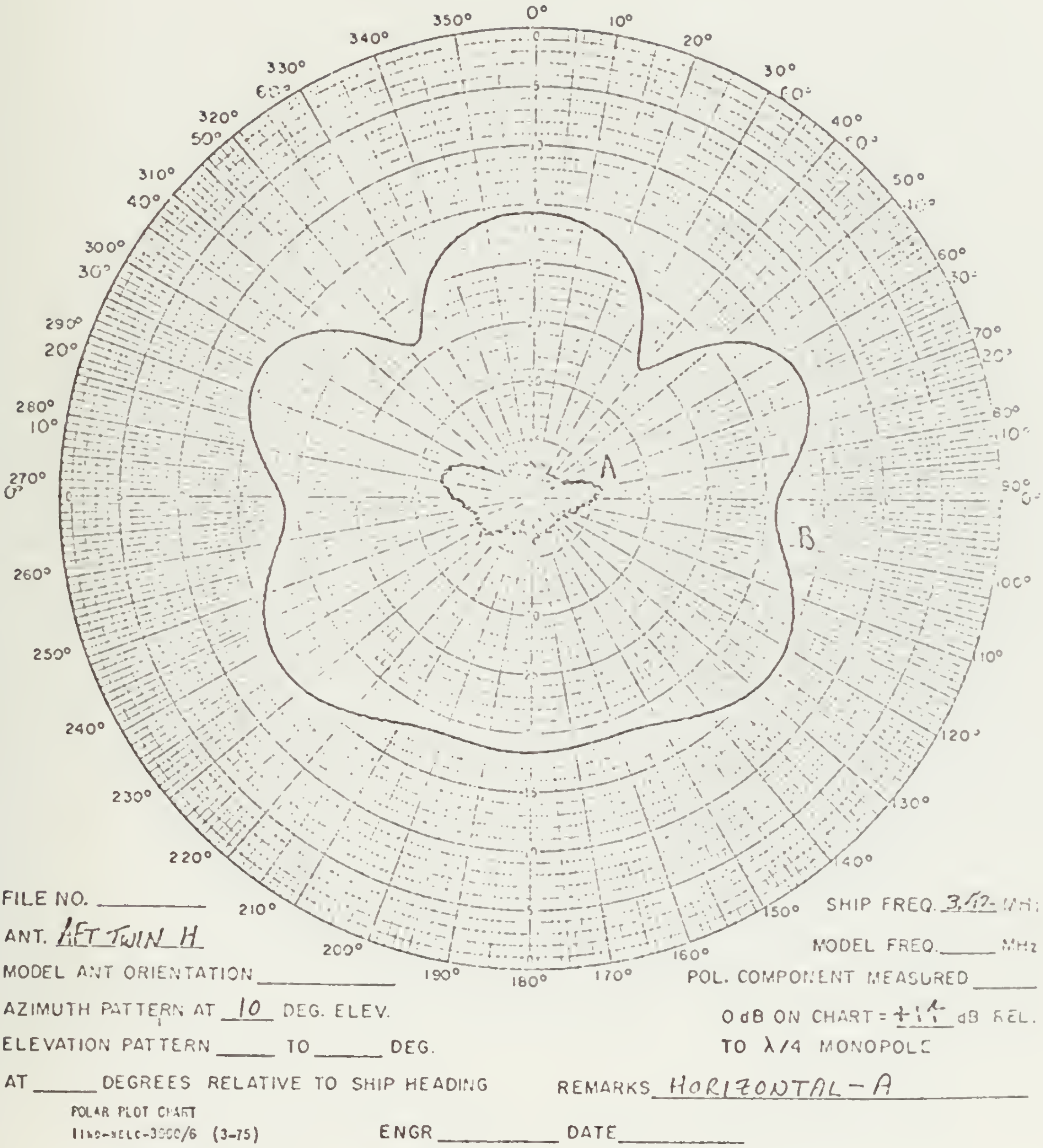


Figure 64

Twin whip radiation at 10 degrees elevation, 3.42 MHZ

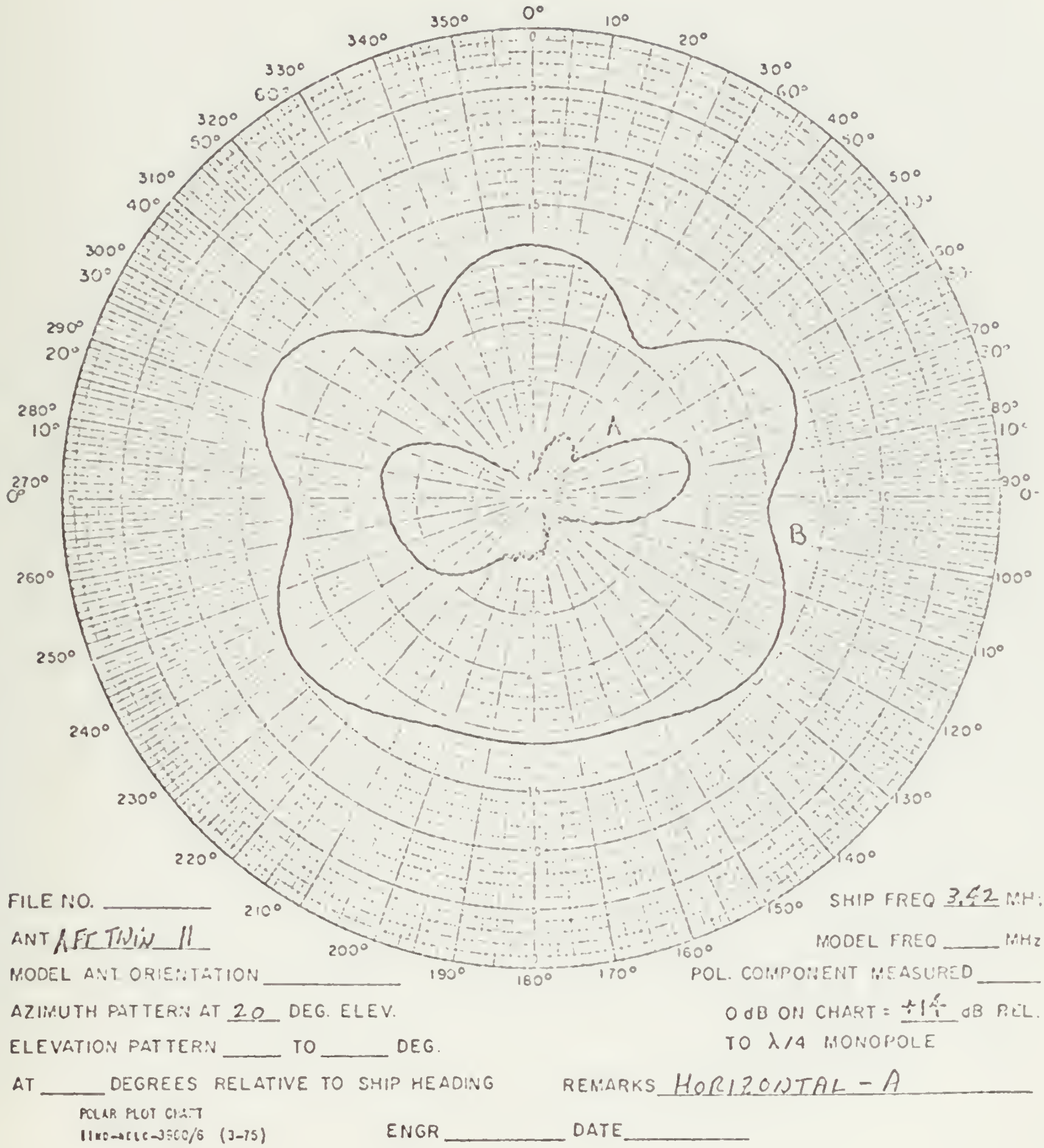


Figure 65

Twin whip radiation at 20 degrees elevation, 3.42 MHZ

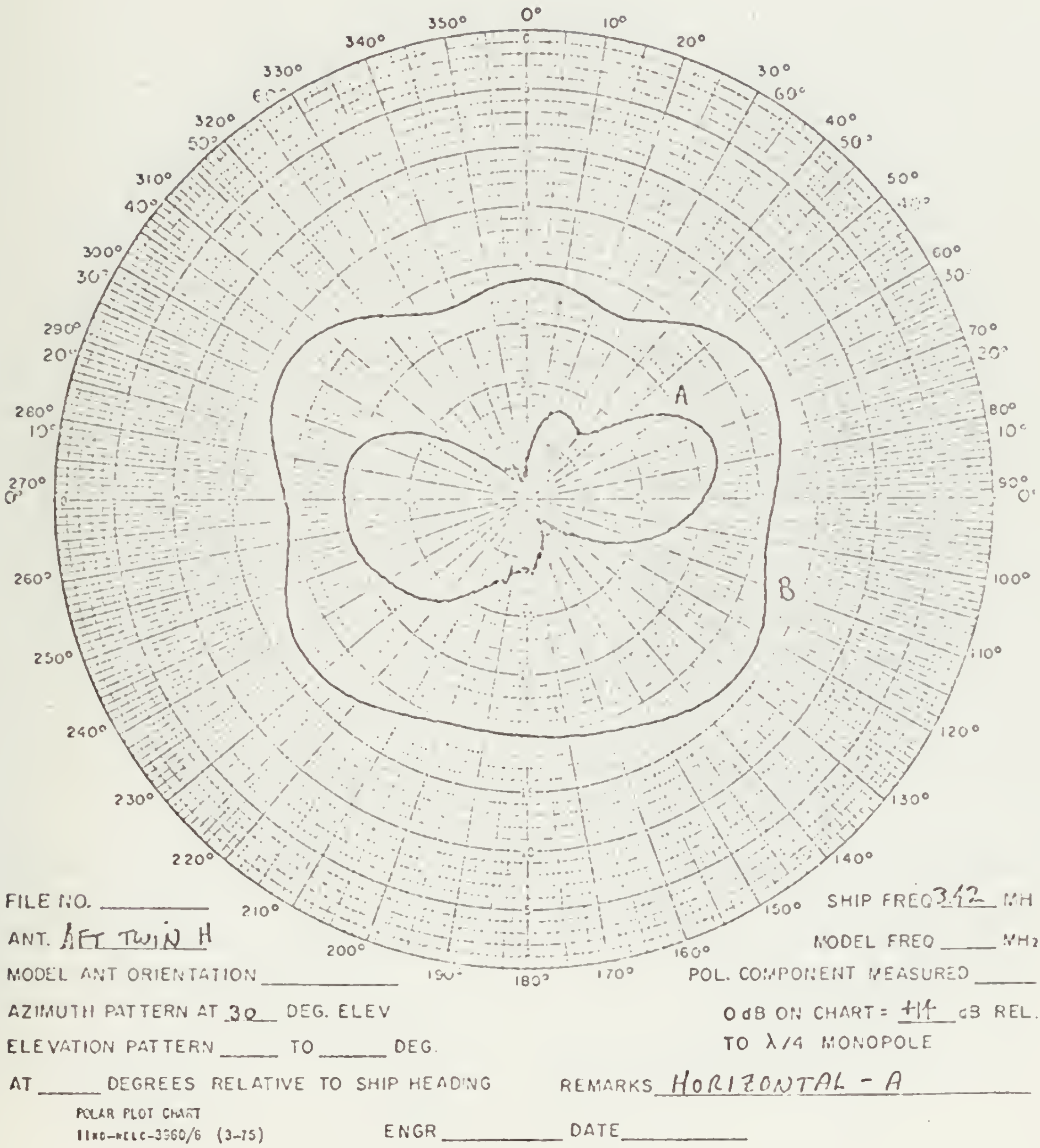


Figure 66

Twin whip radiation at 30 degrees elevation, 3.42 MHZ

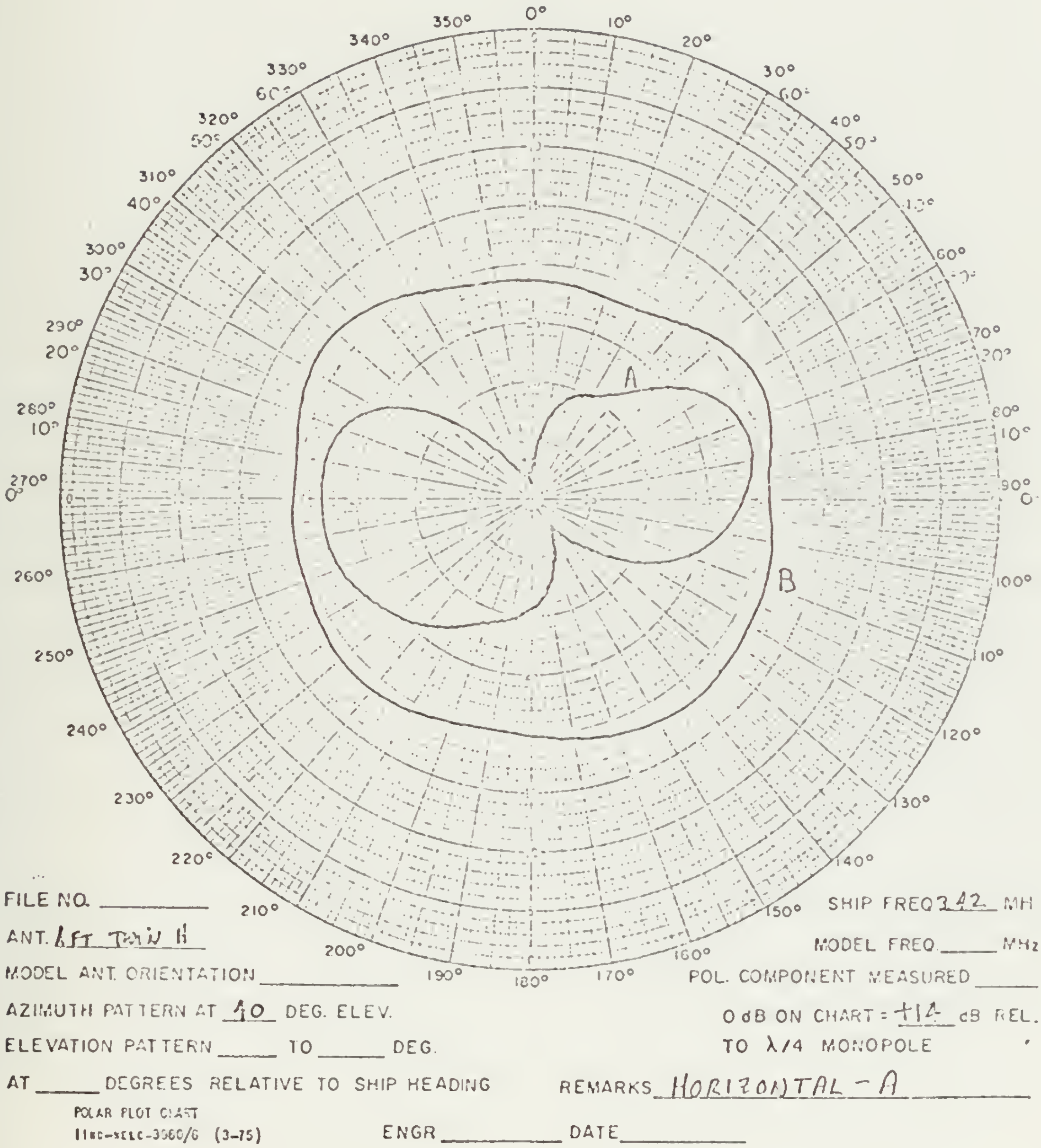


Figure 67

Twin whip radiation at 40 degrees elevation, 3.42 MHZ

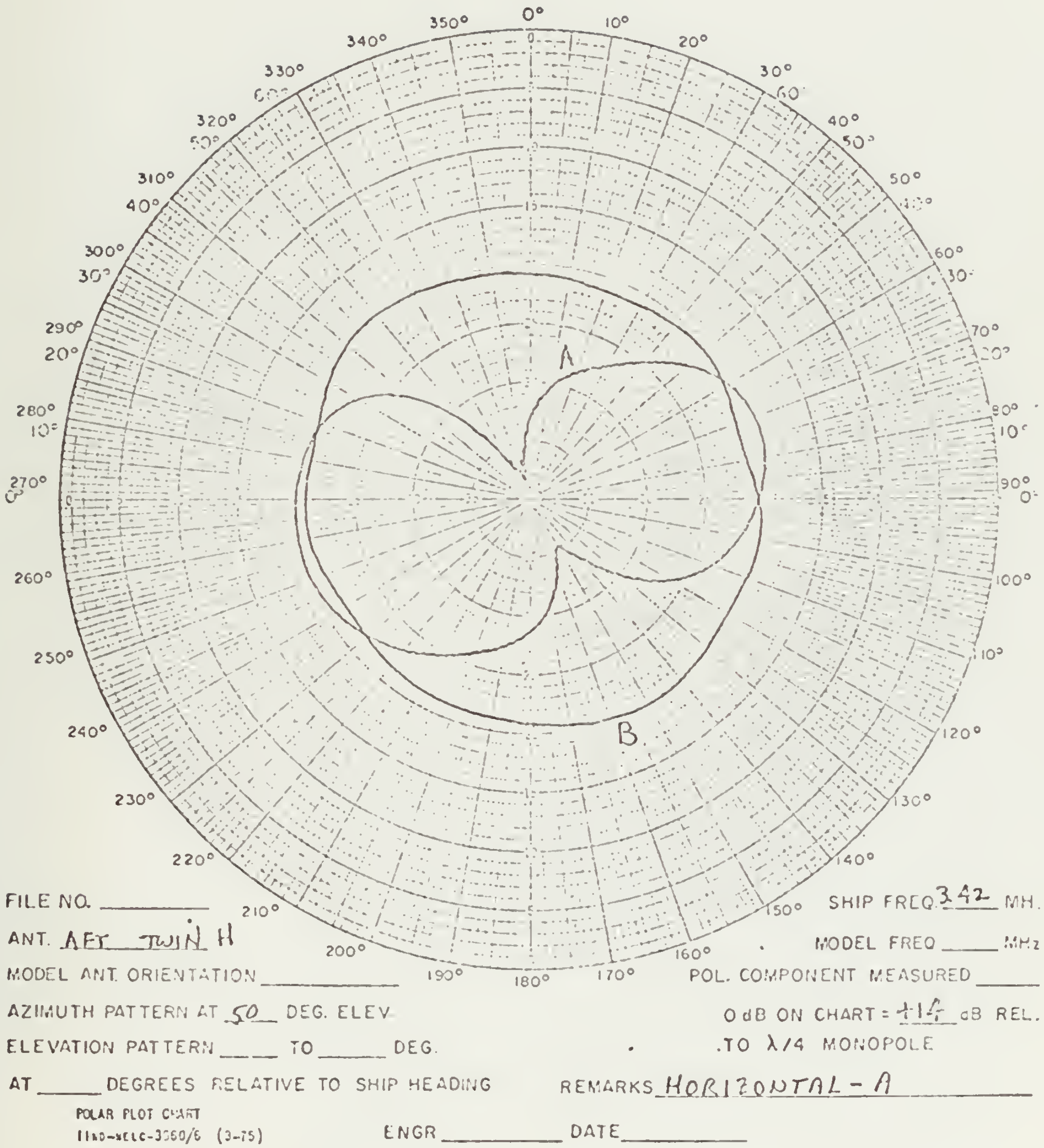


Figure 68

Twin whip radiation at 50 degrees elevation, 3.42 MHZ

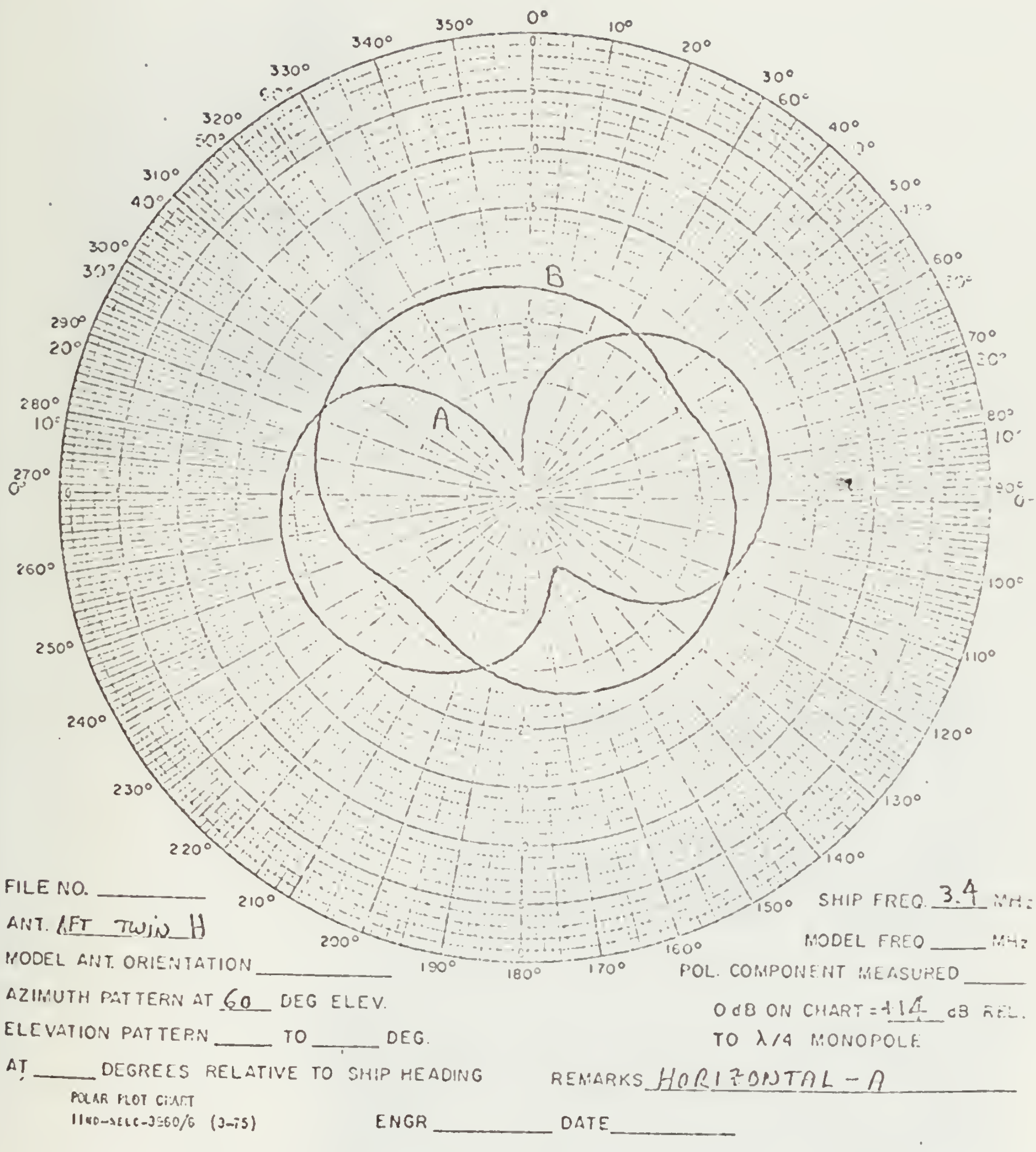


Figure 69

Twin whip radiation at 60 degrees elevation, 3.42 MHZ

Figure 70

Ship's Stern

Figure 71

Ship's Side

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Thesis
H7565 Hopper
c.1 The horizontally polarized dipole antenna as a solution to the problems of high frequency short range communications.